Journal
of
The Franklin Institute
Devoted to Science and the Mechanic Arts

Vol. 197 JANUARY, 1924 No. 1

HIGH-VOLTAGE PHENOMENA.*

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I. INTRODUCTION.

For a number of years the author has been actively engaged in research in various high-voltage phenomena. This work has been done from the standpoint of pure research to determine fundamental principles and from the standpoint of practice to better the insulation of apparatus, to extend transmission voltages and to determine means of protecting transmission lines and buildings from lightning. By combining pure and applied research a much broader view is obtained, and there is no better test of theory than to attempt to apply it to practice in a simple way. It will often be found that essential factors have been overlooked.

In the following discussion of high-voltage phenomena the practical as well as the theoretical viewpoint will be kept in mind.

While it is the particular object of this paper to treat the author's recent investigations at extremely high sixty-cycle and lightning voltages, it will be necessary to refer to the earlier work from time to time for the purpose of coördination. Laws of corona, spark-over, etc., determined at lower voltages but which have been found to apply at the higher voltages, will be given for convenience in the appendix.

* Presented at the meeting of the Institute held Thursday, November 15, 1923.

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II. RESEARCH WITH HIGH SIXTY-CYCLE VOLTAGES.

Within the last two years the author has carried on extensive research work at voltages up to 1,000,000 volts above ground, 1,500,000 single-phase and 1,000,000 three-phase sixty-cycle root mean square values.

Corona laws established at lower voltages were checked as well as spark-over values of needle gaps, sphere gaps, line insulators and other typical electrodes. The same laws and curves were found to apply with no apparent discontinuity. The experimental data will be discussed.

CORONA.

Visual.—Visual corona tests made with large parallel conductors at very high voltages confirm the law established at the lower voltages (see equation in the Appendix). A comparison of measured and calculated values is given in Table I.

TABLE I.

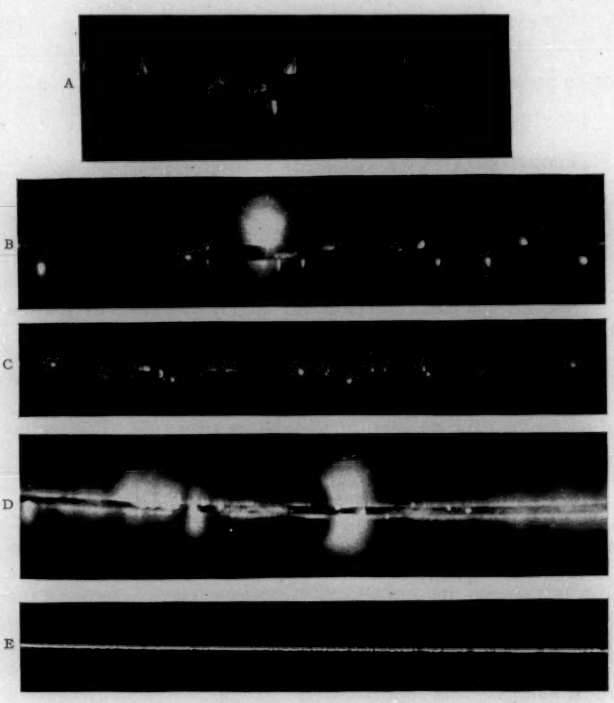
Corona on Parallel Brass Tubes.
(*Sixty Cycles.*)

Spacing.		Visual Corona Voltages Effective $\delta=1$	
Inches.	Cm.	Calculated.	Observed.
Diameter 3.5 inches – 8.9 cm.			
75.5	192	790	730
111.5	283	876	895
147.5	375	915	915
183.5	466	990	990
Diameter 1.75 inches – 4.45 cm.			
73.7	188	490	490
109.7	275	538	560
145.7	370	568	600
183.5	463	604	675
Diameter 1.0 inch – 2.54 cm.			
73	185	340	370
109	277	364	380
181	460	402	415

The agreement is very good. Corona at very high voltage is shown in Fig. 1.

Loss.—The quadratic law seems to hold at the higher voltages (see Appendix). One peculiarity of the very high-voltage line is that the corona loss increases rapidly with a slight percentage

FIG. 1.



Appearance of corona on conductors at supervoltages under different conditions.

A—900 kv.; 3.5-inch tube; 144-inch spacing.
B—800 kv.; 1.75-inch tube; 144-inch spacing.
C—500 kv.; 1.0-inch tube; 72-inch spacing.
D—780 kv.; 1.0-inch tube; 108-inch spacing.
E—800 kv.; 0.04-inch tube; 144-inch spacing.

increase of voltage above the critical point. This is so because the loss increases as the square of the difference between two

voltages. At the higher voltages a small percentage increase means a large actual voltage increase. This is well illustrated by comparing the loss on a line with a 1000 kv critical voltage and a line with a 220 kv critical voltage for a 10 per cent. increase in voltage.

For 1000 kw:

$$p = 0.08\ (578-578)^2 = 0$$

at 10 per cent. increase above the critical voltage

$$p = 0.08\ (635-578)^2 =$$
$$= 0.08\ (57.8)^2 = 260 \text{ kw/mile}$$

For 220 kv:

$$p = 0.05\ (127-127)^2 = 0$$

for 10 per cent. increase

$$p = 0.05\ (140-127)^2$$
$$= 0.05\ (12)^2 = 7.2 \text{ kw/mile}$$

Smooth conductor surfaces are highly desirable to prevent large losses at or near the critical voltage.

Conductors stranded in various ways have been studied recently. For a given diameter, the maximum voltage is obtained from a smooth tube. For the same diameter, a cable is usually good for only 85 per cent. of the voltage of a tube. This ratio is called the irregularity factor. It is very important to consider this factor carefully at the higher voltages.

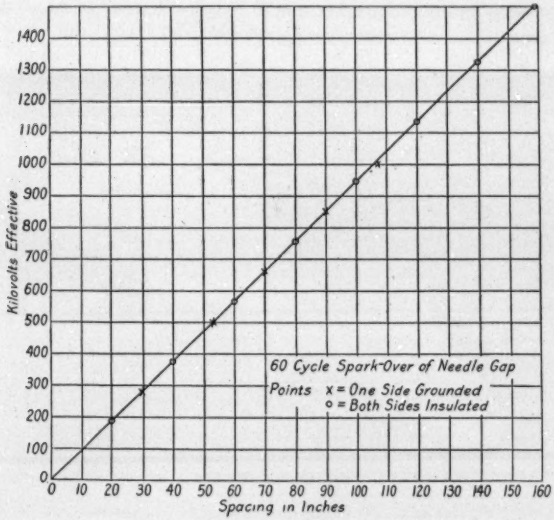
With conductors of about one inch in diameter the seven-strand cable is impracticable. The larger strands become mutilated in manufacture, and the irregularity factor is lower than on cables of a greater number of strands. For new cables, one inch in diameter, the irregularity factor was found to be about the same for cables of 19, 37 and 61 strands and varied from .80 to .85. The 37-strand cable was slightly the best. In other types of conductors and in mutilated cables it was lower. The lowest value obtained was approximately .70. It is important to have the individual strands of the outer layer free from mutilation and evenly placed. Projecting irregularities should always be avoided. On new types of conductors the irregularity factor should be considered carefully.

Measurements were also made on conductors, each of three or more wires of the same potential placed closely together.

SPARK-OVER.

Needle Gap.—The needle gap spark-over curve is given in Fig. 2 up to 1,500,000 volts effective. It will be noted that the curve is continuous from the low to high voltages. There is con-

FIG. 2.



siderable variation in this curve with atmospheric conditions. Fig. 3 shows a single-phase spark-over at 1,500,000 volts.

Spheres.—The spark-over voltage curve for spheres is given in Fig. 4. The values follow the equation established at the lower voltage. (See Appendix.)

Insulator Spark-over.—Fig. 5 gives the spark-over values for standard ten-inch disc suspension insulators. The curves are continuous from the lowest voltage to the highest voltage.

THREE-PHASE ARCS.

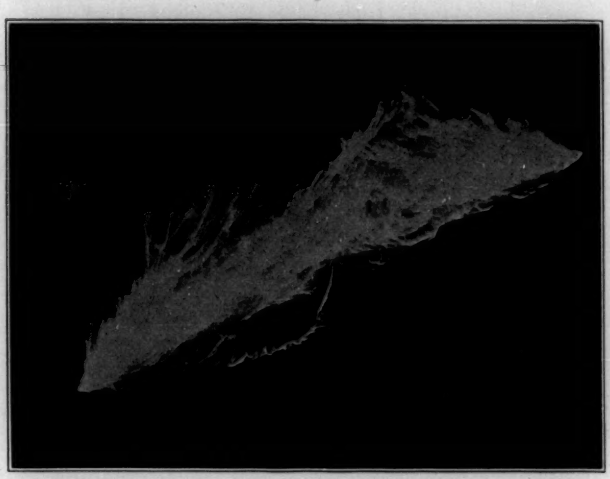
(Comparison of Single-phase and Three-phase Spark-over Voltages.)

The relation between voltage and sparking distance of three-phase arcs apparently had not been investigated until the present

tests were made. In this investigation three-phase sparking distances were measured from very low voltages up to 1,000,000 volts. The standard arrangement was to place the three electrodes at the corners of an equilateral triangle.

The peculiarities of the three-phase spark are that the spark-over voltage is usually lower than for single-phase spark-over; the

FIG. 3.



Photograph of 1,500,000 volts effective, or 2,100,000 volts maximum single-phase arc between points. Distance = 14 feet. 60 cycles.

spark forms in *Y* if there is no dissymmetry; the spark-over does not take place at the instant of *highest* voltage *between conductors*.

The maximum difference in the spark-over voltage between single-phase and three-phase for a given electrode spacing is theoretically 15.5 per cent. These peculiarities come about because of the rotating electrostatic field. The same characteristics are noted in corona formation where for a given size of conductor and spacing corona occurs at a 15.5 per cent. lower voltage for three-phase than for single-phase.

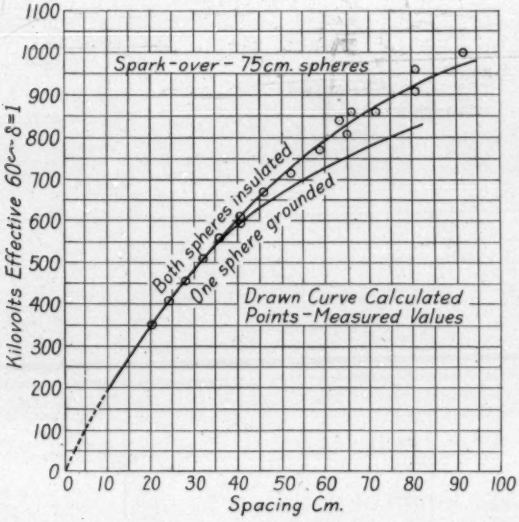
The reason for the above peculiarities is simple. The capacities for single-phase and three-phase electrodes may be represented

as in Fig. 6, where the capacities to neutral are equal. With equal voltages to neutral the maximum stress would be the same for either the three-phase or single-phase arrangement. This follows because

$$\psi = ce$$

and the stress at the conductor is proportional to the flux density, or to the flux, where the conductors are of equal size. With equal

FIG. 4.



neutral voltages, however, the voltages between lines would have the ratio

$$\sqrt{\frac{2e}{3e}} = 1.155$$

This means that for a given maximum stress the single-phase line-to-line voltage must be 15.5 per cent. higher than the three-phase line-to-line voltage. Since the corona starting voltage depends upon the stress at the conductor surface, it follows that

corona or local break-down will start at a 15.5 per cent. lower line-to-line voltage three-phase than single-phase. If the conductor arrangement is such that the addition of corona to the electrodes will further increase the stress, corona must continue across or

FIG. 5.

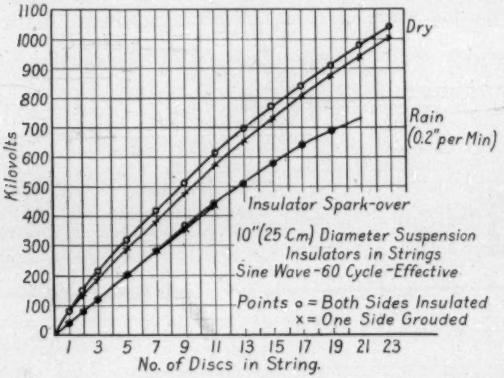
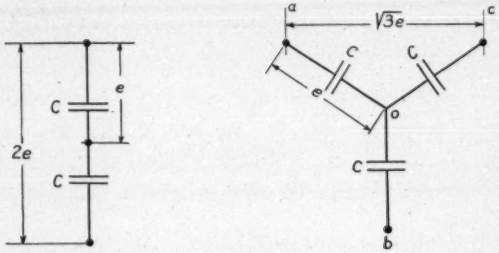


FIG. 6.

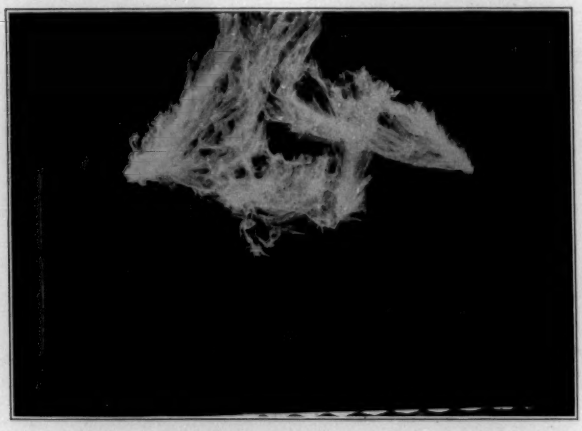


Equivalent capacity arrangement for single-phase and three-phase conductors.

form a spark when once started. This condition obtains for large conductors spaced close together, where any increase in electrode diameter will cause an increase in stress. Corona once started continues to increase the stress as it extends out. Spark

and corona are always simultaneous. The three-phase spark-over should then occur at a 15.5 per cent. lower voltage than for single-phase. Tests bear this out. For small conductors spaced far apart three-phase corona will occur at 15.5 per cent. reduced voltage, but an increase in conductor diameter by corona or otherwise will reduce the stress and there can be no further extension. This changes the field. It is not obvious, therefore, for this con-

FIG. 7*a*.



Three-phase spark-over between needles at one million volts, 60 cycles, sine wave, effective. Needles arranged in an equilateral triangle approximately 10 feet on the side. (Photograph taken along the plane of the needles.)

dition just what difference there should be between three-phase and single-phase spark-over. Spark-over and corona are not simultaneous. Corona forms and enlarges the conductors to a point where the stress is lower than the breakdown stress. Spark-over occurs only at a higher voltage in a modified field. The tests show that even for this type of electrode the three-phase spark-over voltage is lower than the single-phase spark-over voltage.

With the three-phase arrangement corona does not occur simultaneously on all three conductors but rotates. At the instant

of maximum voltage (1.00) between $a-c$ the voltages for $a-o$, $b-o$ and $c-o$ are, respectively, +.50, 0 and −.50. The voltages between $a-b$ and $b-c$ are then −50 and −50. At the instant of maximum stress, and therefore maximum instantaneous voltage to neutral on a, $a-o$ is 58, while $c-o$ and $b-o$ are each −29. The voltage between $a-c$ is then 86, $a-b$, −86 and $b-c$, 0. At the critical voltage the corona or spark on any conductor

FIG. 7*b*.

Three-phase spark-over needles at one million volts, 60 cycles, sine wave, effective. Needles arranged in an equilateral triangle approximately 10 feet on the side. (Photograph taken at right angles to plane of needles.)

begins at the instant of maximum stress. In other words, the corona or spark-over does not start at maximum voltage between lines but at 86 per cent. line voltage.

Spark-over values for different types of gaps are given in Table II. The ratios of single-phase to three-phase spark-over voltages are given in the next to the last column. It will be noted that the difference is of the order expected. No great accuracy is claimed for the very high needle gap voltages where part of the difference is probably due to dissymmetry.

TABLE II.

Comparison of Single-phase and Three-phase Spark-over Voltages for Different Types of Gap.

Needle Gaps.							
Spacing.		Spark-over Voltage. (Kilovolts Effective)				Ratio.	Connection.
		Single-phase		Three-phase		Single-phase	
Inches.	Cm.	Between lines.	Neutral.	Between lines.	Neutral.	Three-phase	
5	12.7	68	34	60	35	1.13	ΔY
10	25.4	109	54	93	54	1.16	"
15	38.2	140	70	130	75	1.08	"
17	40.3	132	76	147	85	1.03	"
20	50.8	176	88	160	92	1.10	"
54	137.0	515	257	450	260	1.14	"
106	270.0	1030	515	865	500	1.19	"
122	310.0	1140	570	925	532	1.24	"
Sphere Gap—6.25 cm. Spheres.							
3.75	9.55	113	56.5	98.5	37	1.15	ΔY
Parallel Wires 0.25 inch–0.64 cm. Diameter Wires.							
3.75	9.55	61	29	52	31	1.17	ΔY
3.75	9.55	61	29	52	31	1.17	ΔY
3.75	9.55	61	29	53	—	1.15	$\Delta\Delta$
Special Connection.							
		52				1.17	

Neutral grounded in ΔY tests with the exception of second test on parallel wires.

PRACTICAL VALUE OF HIGH VOLTAGES.

In addition to its purely theoretical and scientific value just discussed, the production of a million volts also has a practical value. The immediate practical value is its use in testing 220-kv apparatus with the required factors of safety. With the future in mind it is important to learn how to build transformers best suited for operating at voltages higher than those used at present. Even the so-called theoretical investigations of the present become the practical applications of the future.

III. LIGHTNING OR PREDATORY VOLTAGES.

In addition to the steady voltages that force the power current over the transmission line, the line and apparatus are also subjected to certain undesirable or "predatory" voltages. Due allowance must be made for these voltages in design or in the factors of

safety. The lightning arrester should provide a means for allowing these voltages to discharge to ground without permitting excessive power current to follow. These predatory voltages are transients and are either lightning impulses or highly damped oscillations. Continuous undamped high frequency at high voltages cannot exist on a transmission line. This follows because the corona loss increases almost directly with the frequency and would require a power supply of many thousands of kilowatts to maintain it even on a mile of line. The effects of lightning and damped oscillations are very similar.

A study of lightning is desirable for the practical reasons stated above, to better the design of line insulators, lightning arresters and apparatus as well as to determine the best means of protecting buildings, etc.

The study of lightning is also of great theoretical interest. As will appear later, it involves a determination of time periods of less than a millionth of a second duration. Lightning is an electrical explosion. The power over short intervals may be millions of kilowatts. The author has been interested in the study of lightning for a number of years. Part of the study has been made in the field on natural lightning. However, in order to obtain exact data in a reasonable time, it was necessary to produce artificial lightning in the laboratory where all conditions are known and under control. An impulse or lightning generator was devised for this purpose.

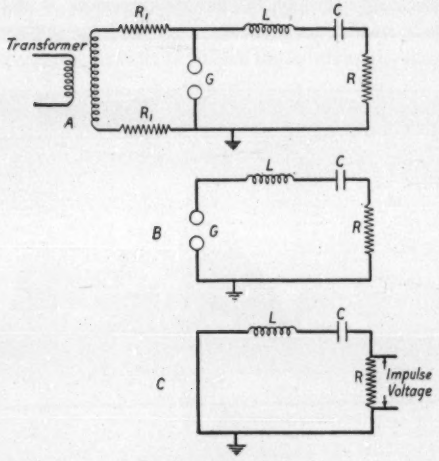
IMPULSE OR LIGHTNING GENERATOR.

The impulse generator giving impulses of a known wave shape was devised in 1913.[1] It has made high lightning voltages possible because it is excited at sixty cycles A.C. and does not require a rectifier or static machine. Its only *present* limit is the available A.C. voltage supply.

The generator circuit is shown in Fig. 8 *A;* its operation is as follows: The gap is set at some desired voltage. The transformer voltage is increased until discharge occurs. At that instant the condenser C is charged up to a voltage corresponding to the gap setting. There is very little drop in the resistance R_1 since the sixty-cycle charging current is relatively small. A dynamic

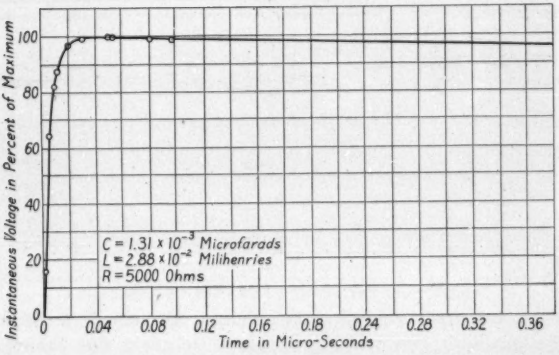
[1] Peek, "The Effect of Transient Voltages on Dielectrics," *A.I.E.E. Trans.*, xxxiv, p. 1857; "Lightning," *G. E. Rev.*, July, 1916.

FIG. 8.



Impulse generator circuit.

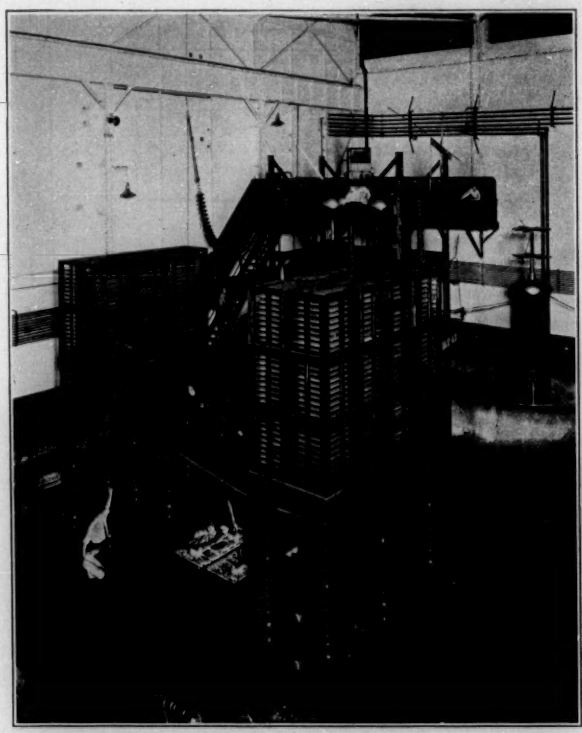
FIG. 9.



Wave shape of lightning used in the tests. Wave shape No. 1. Two-million-volt generator.

arc forms at G and holds. This acts as a switch and the condenser discharges through the known inductance R and the arc. R is a very small fraction of R_1. For the large impulse current

FIG. 10.

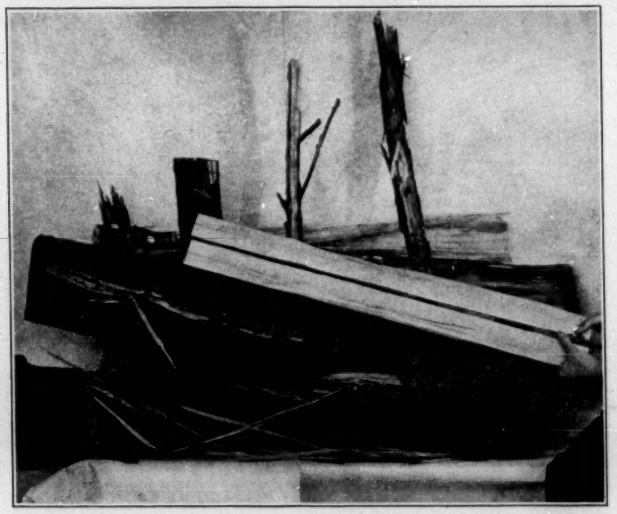


Two-million-volt lightning generator in operation (double exposure made with figures within enclosure to show relative size or scale).

R_1 is practically equivalent to infinity. The circuit producing the impulse is shown in Fig. 8 B or is, in effect, that shown in 8 C. The condenser discharging through the known resistance and inductance causes a transient current that can be readily

calculated. The current produces an impulse voltage drop across *R*. This is the impulse voltage used in the test. A typical wave is shown in Fig. 9, while Fig. 10 shows the generator in operation. Note the *G* gap discharge, as well as the lightning discharge.

FIG. 11.



Wood split by artificial lightning.

The original generator, which gave 200 kv, has been added to from time to time and at present (1923) has been tested to 2,000,000 *volts above ground*.

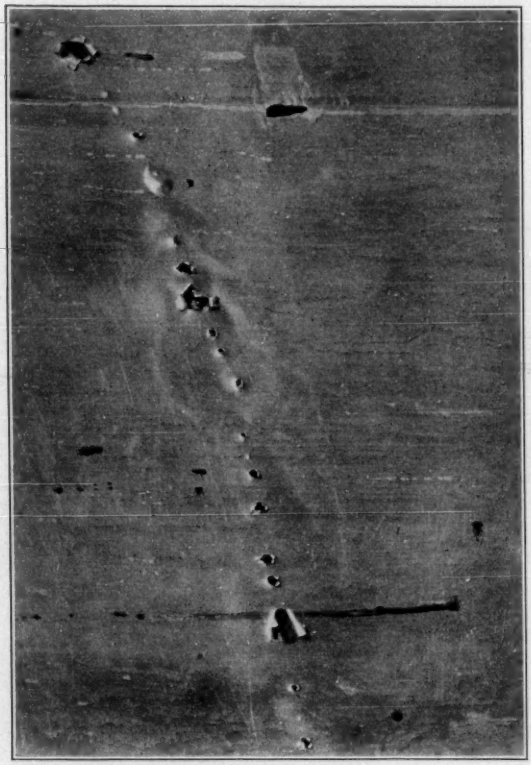
Voltages can be obtained that increase at the rate of millions of volts per second. The power is of the order of millions of kilowatts. The discharge is explosive and gives a loud, sharp report. Currents as high as 10,000 amperes have been obtained.

DESTRUCTIVE EFFECTS OF ARTIFICIAL LIGHTNING.

The large wooden post shown in Fig. 11 was split by a 1,500,000-volt discharge. Longitudinally through the centre of the stick is a hole of less than 1/32 inch (0.8 mm.) in diameter. The wood around this hole has a " fuzzy " appearance, but does

not appear burned. Immediately after being blown apart the wood has an odor of the gases of destructive distillation. Appar-

FIG. 12.



Metal "punctured" by lightning.

ently these gases are formed suddenly by the discharge and produce such high pressures that the wood is blown apart with great violence.

Even metal may be "punctured" as shown in Fig. 12. In this case the metal formed a coating on a glass plate. The lightning discharge punctured the plate to the metal. The holes were apparently caused by the sudden formation of gases between the metal and the glass. A discharge striking through water disrupts it in much the same manner as oil is disrupted at sixty-cycle voltages. The comparative lightning breakdown of air and pure water is given in Table III.

TABLE III.

Transient Disruptive Strength of Water—2.54 cm. Spheres.

Gap Cm.	Impulse kv. (Max.) Water.	Impulse kv. (Max.) Air.	Ratio.
0.1	49.5	3.5	14.1
0.2	86.0	7.0	12.3
0.3	105.5	11.0	9.6
0.5	126.0	17.5	7.2
0.7	137.0	24.0	5.7
1.0	149.0	33.0	4.5
1.3	159.0	42.0	3.8
1.5	165.0	46.0	3.6
	Resistance 20,000 ohms.		
	60° Points—⅛-inch Rods.		
1.0	56.5	25	2.25
2.0	72.0	35.3	2.15
3.0	92.0	41.0	2.25
4.0	113.0	46.5	2.42
5.0	134.0	51.5	2.61
6.0	156.0	56.5	2.76
	Resistance 40,000 ohms.		

Test made in six-inch diameter glass globe with single half-cycles of 500-kilocycle wave.

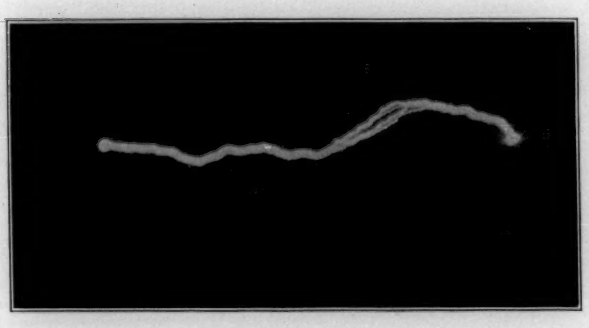
When lightning strikes the earth at some sandy spot its path is often defined by a glass-like tube. This tube which may have branches like a tree is, in fact, sand fused into "glass" by the lightning current. Such tubes are called fulgurites and can be produced by artificial lightning.

Because of the transient and explosive nature of lightning some quite unexpected phenomena frequently happen. Data will now be given on typical types of gaps, the needle gap representing the non-uniform field type, the sphere gap the uniform field, and the insulator representing the surface discharge.

SPARKING-VOLTAGES.

Needle Gap.—The typical discharge from the generator at 1,500,000 volts (max.) between points is shown in Fig. 13. The discharge has a zigzag path and characteristic side flashes of lightning. The lightning spark-over curve for needle gaps is given in Fig. 15. This curve shows that for the particular impulse used (Fig. 9) it requires a voltage approximately 2.25 times the sixty-cycle voltage to spark over a given gap. The author has called the ratio of the impulse voltage to the sixty-cycle voltage the "impulse ratio." The impulse ratio here is 2.25. This is due

FIG. 13.



1,500,000-volt lightning stroke between points. (Note the zigzag path and characteristic side flashes of lightning.)

to time lag and conforms to previous work of the author at lower voltages.[2]

The Sphere Gap.—The recent tests show that the same laws are followed as at the lower voltages. While the impulse spark-over voltage of the needle gap varies with the wave shape of the impulse and is always higher than the sixty-cycle spark-over, the sphere gap is very little affected even for quite steep waves. The sphere gap thus offers a means of measuring transient voltages over a considerable range. However, in measuring such voltages, it is important to have limited series resistance. Series resistance above a critical value will give the sphere the characteristics of the

[2] F. W. Peek, "The Effect of Transient Voltages on Dielectrics," *A.I.E.E. Trans.*, xxxiv, p. 1857, 1915.

needle gap. It takes time to charge the capacity of the sphere through the resistance.

This is illustrated by the data in Table IV.

TABLE IV.

Effect of Series Resistance in Increasing Time Lag.

Applied Lightning Voltage. kv (Max.)	Series Resistance. (Ohms)	12.5 cm. Spheres Gap cm. Testing.	60-cycle Spark-over. kv (Max.)
106	0	3.95	106
106	5,000	3.30	92
106	10,000	2.80	80
106	30,000	2.05	59

Constant lightning voltages were applied to the sphere and series resistance. As the sphere resistance was increased it was necessary to reduce the gap as indicated in order to obtain spark-over with the same applied impulses. The effect of series resistance increases with increasing wave front. This arrangement may be used, therefore, to indicate the duration of a transient while the wave front may be measured by the voltage across an inductance. Fig. 16 shows a lightning discharge between spheres (approximately 10,000 amperes). The light of the discharge is blinding, while the noise is terrific.

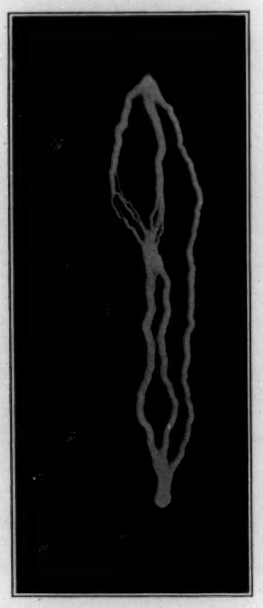
Line Insulators.—Investigation at the lower voltages showed that the wet and dry lightning spark-over voltages of insulators were equal. Tests made at the higher voltages confirm these data. Typical sixty-cycle and lightning arcing characteristics for shielded and non-shielded insulator strings are shown in Fig. 17. The shield consists of a metal ring at the line end of the string. It serves to distribute the voltage evenly between the units as well as to direct the arc away from the string.

These tests are of practical importance since lightning voltages higher than these rarely occur on operating transmission lines. The lightning spark-over voltage was found to be twice the sixty-cycle spark-over voltage. The impulse ratio was increased by the shield. The wet and dry lightning flashes clear the shielded string while on the non-shielded string the flash cascades and is likely to rip off the skirts.

It will be noted that the three typical gap arrangements have different characteristics. Both the needle gap and the insulators

require a lightning voltage about double the sixty-cycle voltage to cause spark-over, while the sphere spark-over voltage is the same for sixty-cycle and a wide range of impulse voltages. This characteristic is of great practical importance since it is desirable to have an arrester gap that discharges at a low lightning voltage

FIG. 14.



Three 1,500,000-volt lightning strokes between points.
(Note that successive strokes do not follow the same path.)

and to design insulators that have a high lightning spark-over voltage. The reason for this is time lag and it seems worth while to discuss it briefly.[3]

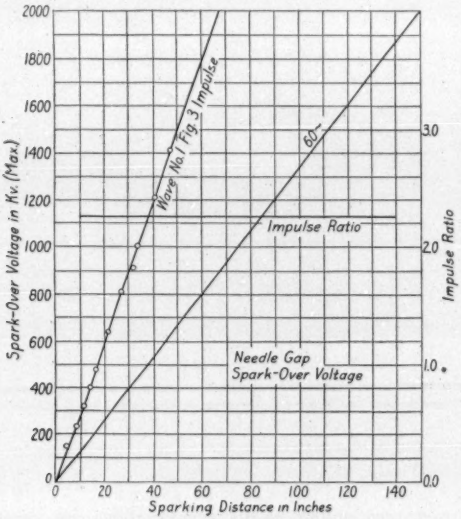
Time Lag.—A fixed minimum voltage is required to spark-over a given gap when the time of application is not limited.

[3] F. W. Peek, Jr., "The Effect of Transient Voltages on Dielectrics," *A.I.E.E.*, xxxiv, p. 1857; *G. E. Rev.*, July, 1916.

Energy is necessary to rupture gaseous, liquid and solid insulation; this introduces a time element.

Referring to Fig. 18, the spark-over voltage of a given needle gap is e_1, and always practically constant, if the time of application is not limited. Spark-over may take place after the continuously applied voltage, e_1, has been on for some time t_1. If a

FIG. 15.

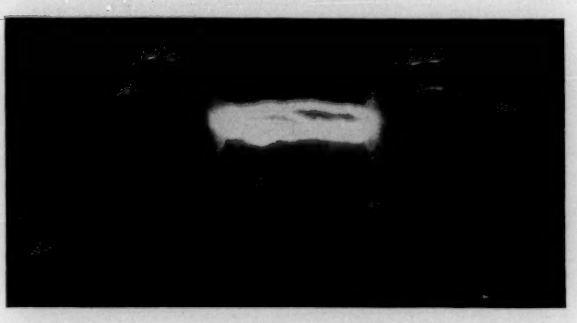


Lightning spark-over curve between points.

voltage increasing at a rapid rate, as represented by A in Fig. 18, is applied, spark-over will not take place when the continuously applied spark-over voltage, e_1, is reached, as the time t_1 is required at this voltage. The spark will begin to form when the voltage reaches the value e_1, however. The voltage will, therefore, rise above e_1, and spark-over will take place after the time, t_2, has elapsed and the voltage has risen to e_2. When the voltage is applied at a more rapid rate along wave B, the spark, as before, will begin to form when voltage e_1 is reached. The voltage will

continue to rise and reach the value e_3, during the time t_3, before the spark-over occurs. Thus, on account of the time lag, when voltage is applied at a very rapid rate, as by an impulse, spark-over does not occur when the continuously applied breakdown voltage is reached. The voltage "over-shoots" this value during the time that rupture is taking place. The excess in voltage is greater, and the time lag less, the greater the rate of application. The time lag for any given gap or insulation has thus not a fixed value but

FIG. 16.



Lightning discharge between spheres. (Note thickness of discharge.)

depends on the wave shape of the impulse or rate of application of the voltage. In making a study of such phenomena it is necessary to use certain definite wave shapes. Fig. 19 shows the impulse voltage-time characteristics for needle gaps. The impulses used in this test were single half-cycles of sine waves. Note that the impulse spark-over voltage is not greatly above the continuously applied or sixty-cycle voltage when the time is over 5 micro-seconds; that is, when the time of application is comparatively long there may be a considerable variation of this time without an appreciable change in the spark-over voltage. The continuously applied (sixty-cycle or $d-c$, where heating does not occur) spark-over voltage is the lowest voltage at which spark-over can take place.

Waves (1) and (2) (Fig. 20) show actual wave shapes used in obtaining data given in Figs. 21 and 22. Wave (1) is equivalent to a single half-cycle of a sine wave; wave (2) rises to a

maximum at the same rate as wave (1), but has a flat top, or is of much longer duration. Of the two waves shown in Fig. 20 the voltage required to spark-over a given gap is higher for the one of shorter duration or for wave (1). In this figure, where actual

FIG. 17a.

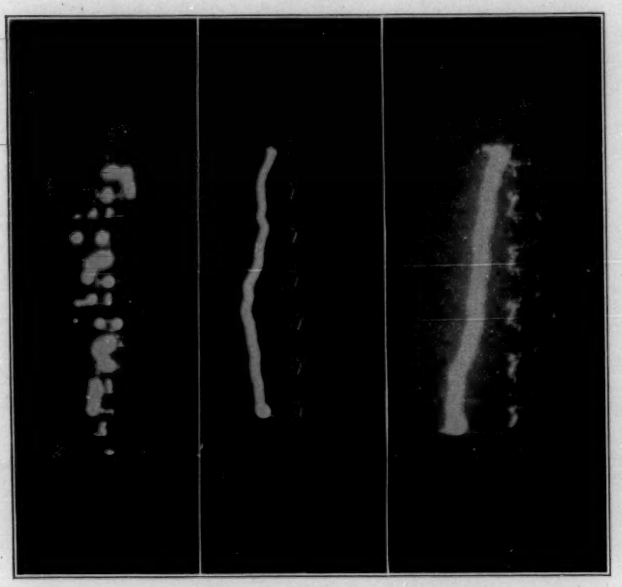
Sixty-cycle spark-over of suspension insulator strings.

1. Dry spark-over on a non-shielded string. Note that arc cascades badly along the entire length of string.
2. Dry spark-over on a string shielded with the ring shield. Note that arc clears string.
3. Wet spark-over on a string shielded with the ring shield. Arc starts through drip then immediately transfers itself clear of string.

test data are given for a 10-cm. gap between needles, spark-over results at 180 kv for wave (1), while for wave (2) spark-over results at 104 kv. The spark-over at sixty cycles is 75 kv. The time that wave (1) is above the continuously applied breakdown voltage is 0.95 microsecond, wave (2), 2.70 microseconds. The impulse and continuously applied needle gap spark-over curves are given in Fig. 21. An examination of Fig. 21 shows that the

impulse spark-over voltage of needles is always higher than the continuously applied spark-over voltage. For instance, with wave (1) the impulse spark-over voltage for a 10-cm. gap is 180 kv, or 2.4 times the sixty-cycle or continuously applied voltage. The

FIG. 17*b*.



Lightning spark-over of suspension insulator strings.
1. Dry spark-over on a non-shielded string. Note that arc cascades badly along the entire length of string.
2. Dry spark-over on a string shielded with a ring shield. Note that arc clears the string. Voltage = 1,200,000 volts.
3. Wet spark-over on a string shielded with the ring shield. Note that arc clears the string. Voltage = 1,200,000 volts. (Note, also, the drip along the string and the rain-drops which appear stationary in space since the light of the arc lasted less than a millionth of a second.)

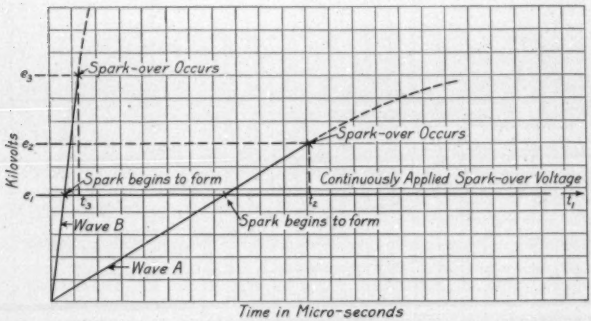
ratio of the impulse spark-over voltage to the continuously applied voltage has been termed the impulse ratio.

The time to spark-over a gap varies with the spacing and shape of the electrodes. For a given sixty-cycle voltage setting the time required to form a spark is greatest for gaps between points and least for gaps between well-rounded surfaces. For spheres,

the time lag is so small that discharge takes place before the impulse voltage can rise appreciably above the continuously applied or sixty-cycle spark-over voltage. This is shown in Fig. 22, where the drawn curve is the sixty-cycle curve while the impulse spark-over voltages for waves (1) and (2) are represented by crosses and triangles.

The needle gap requires the maximum time of any gap as considerable air must be ionized before spark-over can result. Another way of considering it is that the corona increases the

FIG. 18.



Diagrammatic illustration of why the lightning or impulse spark-over voltage is higher than the continuously applied.

capacity and places resistance in series with it as it forms. It requires time to charge a condenser through resistance.

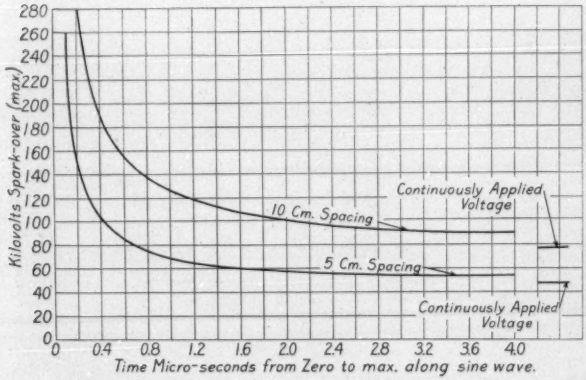
On the other hand, spheres are very little affected because corona does not precede spark-over, and the discharge is small and confined to a short path. The field is very nearly uniform and ruptures start everywhere along the path between the electrodes at approximately the same time.

Corona.—Lightning voltages cause corona in the same manner as continuously applied voltages. Corona produced by lightning voltages of less than a microsecond duration (millionth of a second) can be readily seen. It is also easy to tell at a glance whether the impulse is positive or negative. The author has found that in general corona produced by impulse voltages follows the same law as corona produced by continuously applied voltages.

LIGHTNING ON TRANSMISSION LINES.

Most lightning disturbances on transmission lines occur by electrostatic induction and not by direct stroke. A charged cloud causes an electrostatic field to earth. Part of the field will terminate on a transmission line within its area. The line is said to have a "bound charge." If the voltage between earth and cloud becomes high enough a lightning flash will occur. Although this flash may be a mile away from the line the charge on the line is released and the insulated line increases from earth potential to

FIG. 19.

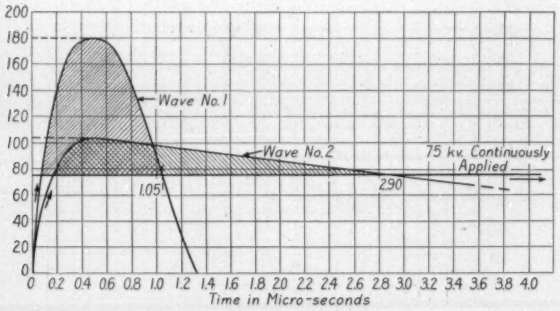


Time and voltage to spark-over needle gaps with a sine wave impulse.

some value above with polarity opposite to that of the cloud. The effect is of a voltage suddenly applied between line and ground. The field that extended between line and cloud now extends between line and ground. The voltage wave travels over the line at the velocity of light. If the line insulators are strong enough or have a high enough impulse ratio it may travel to the powerhouse to breakdown apparatus or to be harmlessly discharged to ground over the arrester if it has low resistance and low impulse ratio. As this lightning wave travels over the line it becomes gradually dissipated by losses. The voltage that the line assumes at the instant of discharge is that of the equipotential surface at the point in which the line is located. This is a certain

percentage of the potential of the cloud above earth or, in fact, a certain percentage of the voltage of the lightning bolt. In studies in Colorado the author has actually measured induced lightning on transmission lines as high as 500,000 volts. Insulator flash-overs have occurred that indicate induced voltages as high as 1,500,000 volts, although the greater percentage of voltages induced on transmission lines are very much lower than this. These figures are given, because, as will appear later, they offer a means of estimating the voltage of a lightning flash. It seemed

FIG. 20.



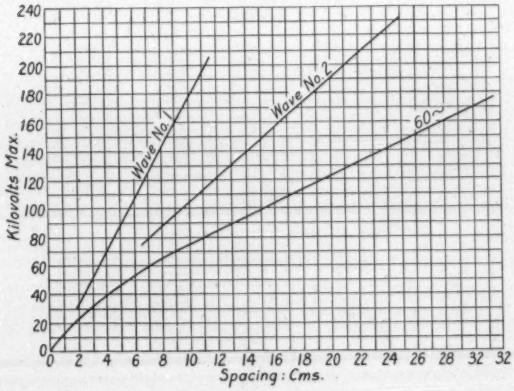
Continuously applied and impulse voltages to just cause spark-over of a 10-cm. gap between needles.

desirable to the author to study these phenomena in the laboratory in connection with the lightning generator, making clouds, transmission line, buildings, distances, etc., to scale. Although this investigation is not yet complete, the exceedingly interesting results so far obtained will be described.

Induced Strokes—the Ground Wire.—The arrangement for studying direct strokes on transmission lines is shown in Fig. 23. The plate represents the position of the cloud which causes a steady electrostatic field to ground in the vicinity of the transmission line. The complete cloud includes the condenser of the lightning generator. This field is in reality a sixty-cycle A.C. field, but at the instant of discharge of the clouds to earth is in effect a steady field. When the condensers discharge, the charge on the transmission line is released.

The voltage of the cloud P and of the transmission line can be accurately measured; the voltage of the cloud to ground by spheres and the voltage of the lines to ground by small needle gaps mounted to give minimum capacity. The ratio of the conductor diameter to spacing, etc., was selected to correspond to practical conditions. Tests were made with the transmission line grounded through high resistance to represent the grounded neutral system

FIG. 21.



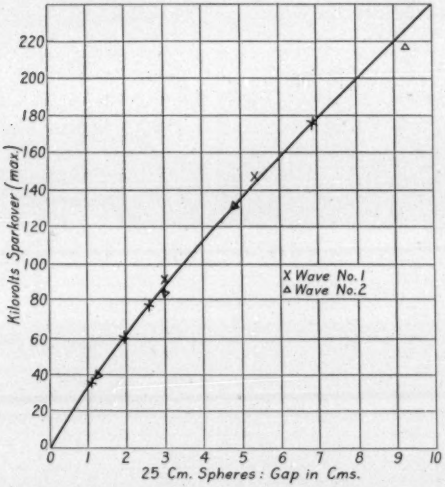
Needle-gap spark-over curves for 60 cycles and for impulse waves Nos. 1 and 2. Wave No. 1—single half sine wave impulse. Wave No. 2—Impulse with steep front, but with a long tail.

and also without grounds. The results were practically the same. The model cloud and line are shown in Fig. 24.

The first tests were made with a cloud height corresponding to about 216 feet. This is, of course, an improbable condition. The more probable condition is that in Table V with the cloud 864 feet above ground. However, it can be readily shown mathematically that since the field is practically uniform between the line and earth the induced voltages depend only on the voltage gradient in this part of the field. A given voltage gradient may be caused by a high cloud and high cloud voltage or a low cloud with low cloud voltage. Any condition may thus be simulated by a fixed cloud distance and varying voltage.

By reducing the line spacing, size of conductor and height to scale, the capacity and inductance *per unit length* remain practically the same as for the full size line. The only factor that does not correspond is the resistance. It is relatively higher. However, it is not believed that this materially affects the results.

FIG. 22.



Sphere gap spark-over curves for 60 cycles and for impulse waves Nos. 1 and 2. Wave No. 1—Single half sine wave impulse. Wave No. 2—Impulse with steep front, but with a long tail. (Drawn curve is for 60 cycles; points are for waves Nos. 1 and 2, as noted.)

The length of the artificial cloud has no particular meaning except that it is long enough to produce a practically uniform field.

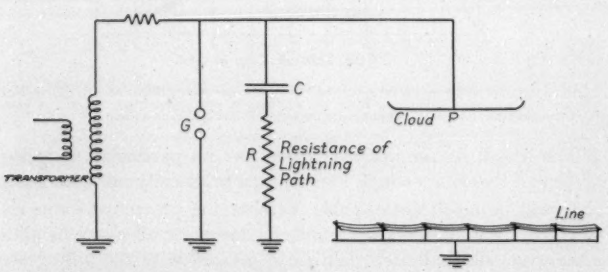
It will be noted from Table VI that the protective value of the ground wire is quite high and the same for all cloud heights as theory would indicate. With one ground wire the voltage is practically cut in half. This also conforms with theory. The last column in Table VI is called the protective ratio. A ratio of .43 means that the induced voltage on the line with a ground wire is .43 of that on a line without a ground wire.

TABLE V.

Actual Size of Model.	Corresponding Size to Scale.		
Cloud—5′ x 7½″ (152 cm. x 229 cm.) Horizontal plate.			
Height of cloud 43½″ (112 cm.)	216′ (66 M.)	432′ (132 M.)	864′ (264 M.)
Height of line 6″ (15.2 cm.) Conductor spacing— 1½″ (3.8 cm.) Conductor diameter— .02″ (.05 cm.)	30′ (9.1 M.) 7.5′ (2.3 M.) 1.2″ (3 cm.)		
Height of line 3″ (7.6 cm.) Conductor spacing— .75″ (1.9 cm.) Conductor diameter— .01″ (.025 cm.)		30′ (9.1 M.) .75″ (2.3 M.) 1.2″ (3 cm.)	
Height of line 1½″ (3.8 cm.) Conductor spacing— .375″ (.95 cm.) Conductor diameter— .005″ (.012 cm.)			30′ (9.1 M.) 7.5′ (2.3 M.) 1.2″ (3 cm.)

The ground wire reduces the voltage by reducing the initial charge or the flux terminating on the line and by increasing the

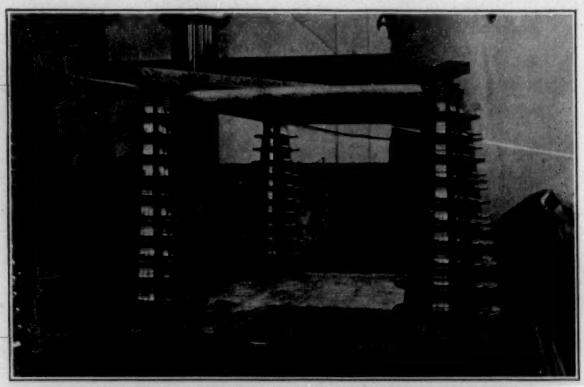
FIG. 23.



Connections used in studying induced voltages on transmission lines.

capacity to ground. This capacity has in series with it, however, the inductance and resistance of the ground connections. If the lightning discharge took place without time the initial instan-

FIG. 24*a*.



Study of voltages induced upon transmission lines. Photograph shows overhead cloud and a section (to scale) of one of the lines studied during the investigation.

FIG. 24*b*.

Short section of a three-phase line with overhead ground wire upon which a study was made of induced voltages of lightning. Photograph shows one of the "towers" and one of the spark-gaps used to measure voltage at this point.

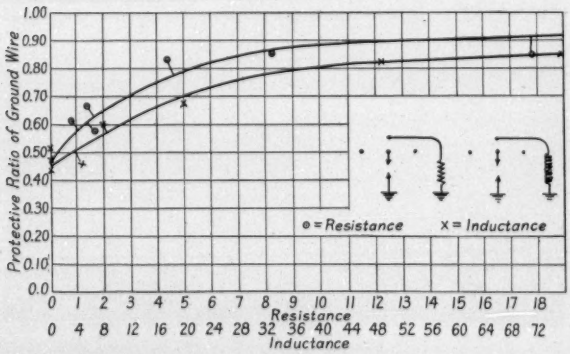
TABLE VI.

Induced Voltages on Transmission Lines with and without Ground Wire—Protective Value of Ground Wire—Line by Scale 30′ High (9.1 M.); Conductors Spaced 7.5′ (2.3 M.); Size 1.2″ (3 cm.); Lightning Voltage 372 kv.

Arrangement.	Scale Distance to Cloud above Line.	Induced Voltage.	Per cent. of Lightning Voltage Induced on Line.	Protective Ratio* of Ground Wire.
No ground wire o o o	216′ (66 M.)	33	9	—
Ground wire above centre line o o o	216′ (66 M.)	14.7	4	.43
Three ground wires above line o o o	216′ (66 M.)	8.7	2.3	.26
No ground wire o o o	864′ (264 M.)	8.0	2.1	—
Ground wire above centre line o o o	864′ (264 M.)	3.4	.9	.43
No ground wire o o o	Irregular Field	6.3	1.70	—
Ground wire o o o	Irregular Field	3.3	.9	.52

*Voltage without ground wire divided by voltage with ground wire.

FIG. 25.



Effect of resistance and inductance upon the protection offered by an overhead ground wire.

taneous voltage would be the same with or without the ground wire. The tests show there is sufficient delay so that the inductance does not produce an appreciable effect. Inductance was added to the ground wire connection with the result shown in Fig. 25. It shows that the great possible protective value of the ground wire could be greatly reduced in practice by resistance in

FIG. 26*a*.

Lightning hitting the overhead ground wire of a transmission line during study of direct strokes and induced lightning voltages on a three-phase line during a storm.

the ground connection or by considerable distance between grounds causing high inductance.

Direct Strokes.—The ground wire is also of value in case of direct stroke. The lightning voltage was increased to a value sufficient to cause discharges to ground in the transmission line area. With the cloud at a height of 216 feet and the line 30 feet high, two flashes out of twenty-five struck the ground wire. The remainder struck the ground. This is more extreme than any practical case. With the cloud 864 feet and the transmission 30 feet high, two out of fifty flashes struck the ground wire, while the remainder struck the ground. This latter case more nearly represents practical conditions. (Fig. 26.)

PROPAGATION OF LIGHTNING ON TRANSMISSION SYSTEMS.

A study has been made of the propagation of lightning on transmission lines. In the tests described below an impulse with a wave front equivalent to a 5,600,000-cycle sine wave was applied to a short transmission line. The length of this wave from zero to maximum was approximately 36 feet (12 metres). The maximum length of line used was made up of two parallel wires each

FIG. 26*b*.

Lightning striking overhead ground wire of a three-phase line during study of direct strokes caused by an electrical storm passing over a transmission line.

280 feet (85 metres) long, and spaced 3 feet (0.92 metre) apart. The diameter of the wire was 0.4 inch (0.012 cm.). The object of the small wire was to cause high corona loss and thus get alternative effects of a much longer line. The general connection in studying wave propagation is shown in Fig. 27.

The impulse was applied to the line and the voltage measured at the start, in the centre of the line and at the end. Both needles and spheres were used to measure the voltage in order to determine changes in wave front. The spheres measure the correct maximum voltage, while the needles always indicate a lower voltage.

The steeper the wave the lower is the voltage indicated by the needles. The ratio of the sphere and needle voltage, or the impulse ratio, is thus a measure of the steepness of the wave. The higher the ratio the greater is the steepness. Referring to Fig. 27, a 133 kv impulse was applied. The needle gap indicated 56 kv or an impulse ratio of 2.4. At the centre of the line the

FIG. 26c.

Lightning strokes striking down to earth and to an overhead ground wire of a three-phase line during study of lightning protection of transmission system. (Note that one of the strokes to the ground wire is divided near the lower end and is hitting the wire in two places.)

maximum voltage of the wave was reduced 18 per cent. while the wave front was flattened out, as shown by the impulse ratio of 1.7. If the voltage continued to decrease at the above rate it would have a value of 80 kv at the end. Actually, practically double this value was measured; on striking the end the voltages doubled, as would be expected. The wave front was also steepened at the end, as shown by the impulse ratio. Data covering various conditions are given in Tables VII and VIII. Of special interest is the case where an inductance coil is placed at the end of the line when the voltage is over double the applied value.

TABLE VII.

Propagation of Lightning on Transmission Lines.

Test number.	Arrangement Parallel wires.	Start.			Middle.			Start of Inductances or Resistances.			Far End.		
		Voltage (Max.)		Impulse Ratio.	Voltage (Max.)		Impulse Ratio.	Voltage (Max.)		Impulse Ratio.	Voltage (Max.)		Impulse Ratio.
		Sphere.	Needle.		Sphere.	Needle.		Sphere.	Needle.		Sphere.	Needle.	
1	Line 6′ (1.84 metres) long—open at far end	...	..	...	...	..	...		None		191	71	2.7
2	Line 140′ (43 metres) long—open at far end	137	56	2.4	...	..	...		None		194	78	2.5
3	Line 280′ (86 metres) long—open at far end	133	56	2.4	110	64	1.7		None		168	74	2.3
4	Line 280′ (86 metres) long short circuited at far end	139	57	2.4	100	51	2.0		None		0	0	0
											Short circuited		
5	Line 280′ (86 metres) line short circuited at far end by resistance = approximate surge imped. = (850 ohms)	132	54	2.4	99	48	2.1	Resistance = surge impedance 85	47	1.8	End closed		
6	Line 280′ (86 metres) line open with 425 ohm resistance in series on each line	133	54	2.5	104	59	1.8	163	71	2.3	160	71	2.3
7	Line 280′ (86 metres) line open at far end with an inductance coil in series in each line	133	57	2.3	103	55	1.9	146	72	2.0	238	87	2.7
8	Line 280′ (86 metres) closed at far end with an inductance coil in series in each line	134	55	2.4	103	54	1.8	148	64	2.3	0	0	0
								L = .47 mile henries			End closed		
9	Line 280′ (86 metres) open at far end. Inductance shunted by resistance	132	55	2.4	102	56	1.8	153	72	2.1	150	93	1.6
10	Line 280′ (86 metres) end closed by a condenser	136	60	2.3	102	54	1.9	..	..	..	92	44	2.1
11	Single 280′ (86 metres) line ground return-end open	116	51	2.3	..	..	..	..	..	..	158	61	2.6

Size of conductor 0.04″ (0.102 cm.) Spacing 3′ (91.5 cm.). 5000 kc. wave.

TABLE VIII.

Propagation of Lightning on Transmission Lines.

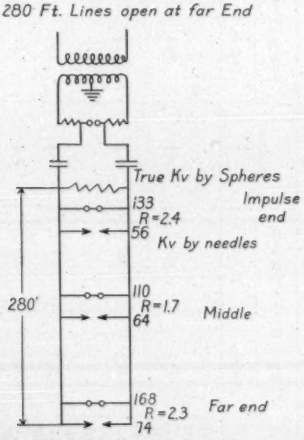
Test Number.	Arrangement.	Start.			Far End.		
		Voltage (Max.) to Ground.		Impluse Ratio.	Voltage (Max.) to Ground.		Impulse Ratio.
		Sphere.	Needle.		Sphere.	Needle.	
12	Single wire 280′ (86 metres) long-open at far end. Impulse between line and ground.....	133	56	2.4	151	65	2.3
13	Two wires connected at start 280′ (86 metres). Volts between wire and ground.....	133	56	2.4	113	62	1.7
14	Single wire 280′ (86 metres) single ground wire 3′ (.91 metre) distance grounded at far end.....	133	56	2.4	146	64	2.3
15	Same as (14) ground wire grounded at start and end.....	133	56	2.4	148	66	2.2
16	Two parallel wires each 280′ (86 metres) connected together at far end. Impulse sent out on one and back on other at total of 560′ (172 metres).....	133	56	2.4	136	61	1.9

Size of conductor 0.04″ (0.102 cm.) Distance to ground 25′. 5600 kc. wave.

MEASUREMENT OF THE VOLTAGE OF A REAL LIGHTNING BOLT.

There has always been considerable speculation as to the voltage of a lightning stroke, and various estimates have been made in more or less complicated or indirect ways. The recent tests have shown that up to about 2,000,000 volts maximum 150,000 volts is required for every foot of spark. The length of the lightning flash as well as the height of cloud, etc., can

FIG. 27.

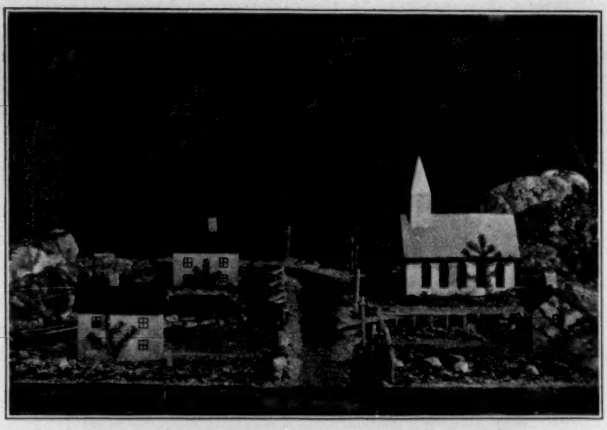


General connections used in studying propagation on transmission lines. Figures give voltage as measured by spheres, impulse ratio and voltage as measured by needles.

be readily estimated. It had been more or less generally concluded, however, that the voltage of the stroke was very much less than would be indicated by the length of the flash, or that when the flash-over started, it in some way continued to great distances at relatively low voltages.

It seems that these tests with artificial lightning with line and cloud to scale offer an almost direct means of measuring lightning voltages. The means is quite simple. In the tests with the model cloud at about 860 feet above the line, it was found that the voltage induced in the line was 2 per cent. of the artificial lightning flash. A condition more nearly corresponding to the condi-

FIG. 28*a*.



Model village built to scale and used in the study of lightning protection of buildings and low voltage lines.

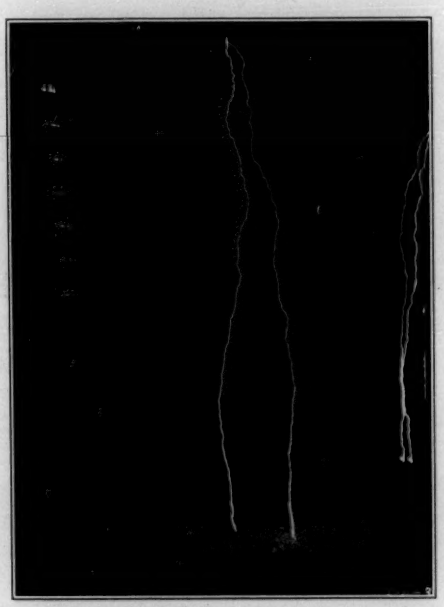
tions of an actual lightning flash would make the induced voltage about 1 per cent. of the lightning voltage with a cloud 1000 feet above the line discharging to earth. But we know, by measure-

FIG. 28*b*.

Artificial lightning stroke from two-million-volt lightning generator striking house and church of model village during study of lightning protection of buildings.

ment, that the voltage induced on an actual line under similar conditions is sometimes of the order of 1,000,000. If this is 1 per cent. of the voltage of an actual lightning flash, the voltage of the flash must be 100,000,000 million volts. This gives a voltage of 100,000 per every foot of spark, which, considering

FIG. 29.



Protective area of a lightning rod. Lightning either strikes the rod or the earth at some distance from the rod. There is thus an area surrounding the rod that is immune. This is illustrated in this figure.

the possible error, indicates that the needle gap spark curve may hold approximately even at these extreme voltages. While the field produced by the charge is probably fairly uniform, it is probable that at the instant before spark-over a needle-like streamer forms and breaks down, then corresponds to the needle gap. The sparking distance probably should generally correspond

to a continuous voltage because there is no transient until after the spark starts.

It thus appears by approximately direct measurement that the order of voltage of a severe lightning stroke to ground may be about 100,000,000. The lightning voltage during a storm will of course vary over a very wide range. The author has observed that during a severe thunderstorm there may be many induced strokes at very low voltages, a smaller number at moderate voltages, and so on, to very few at the extreme voltages.

FIRES CAUSED BY LIGHTNING.

It is stated above that large wooden posts were violently blown apart without any sign of burning. However, wooden logs were easily fired by a stroke from the lightning generator. This occurred when a log contained cracks. Apparently gases were formed from the wood as in the other tests and became ignited in the cracks. The ignited gases in turn ignited the wood. The cracks reduced the pressure and there was no violent tearing apart of the wood.

PROTECTION OF BUILDINGS—PROTECTIVE AREA OF A LIGHTNING ROD.

Tests are under way to determine the best methods of protecting buildings from lightning, as well as to determine the protective area of a lightning rod. In these tests miniature building, clouds, etc., all to scale as in the case of the ground wire were used. These tests, as far as they have gone, show that the lightning rod has real value in preventing destruction in case the house is struck. Whether it increases the chance of being struck is being further investigated. In deciding upon lightning rod protection the economic factor must also be considered. The cost of the insurance must be weighed against the probability of being struck (Fig. 28).

I acknowledge the assistance of Mr. W. L. Lloyd in making the tests.

APPENDIX.

CORONA AND SPARK-OVER FORMULÆ.

Disruptive critical voltage:

$$e_0 = 21.1 m_0 r \delta \log_e \frac{s}{r} \text{ kv/neutral}$$

Power loss:

$$p = \frac{244}{\delta}\ (f+25)\ \sqrt{r/s}\ (e-e_0)^2\ 10^{-5}\ \text{kw/km of single conductor.}$$

Where the conductors are small:

$$p = \frac{241}{\delta}\ (f\ 25)\ \sqrt{\frac{r+\frac{6}{s}+0.04}{s}}\ (e-e_d)^2\ 10^{-5}\ \text{kw/km}$$

$$e_d = 21.1\ m_0\ \delta\ r\left(1+\frac{.30}{\sqrt{\delta r}}\ \frac{1}{(1+230r^2)}\right)\log_e\frac{s}{r}$$

Visual critical voltage:

$$e_v = 21.1\ m_v\ \delta\ r\left(1+\frac{0.30}{\sqrt{\delta r}}\right)\log_e\frac{s}{r}\ \text{kv to neutral}$$

$$\delta = \frac{3.926}{273+t}$$

Where—

e = effective kv to neutral.
δ = air density factor = 1 at 25°C. and 76 cm. bar.
b = barometric pressure in cm.
t = temperature in degrees centigrade.
s = spacing between conductor centres in cm.
f = frequency cycles per second.

For approximate storm loss consider

e_0 = 0.8 of fair weather value.

Irregularity factor (due to roughness of conductor surface):

m_0 = 1 for polished wires.
= .98 to .93 for roughened or weathered wires.
= .87 to .83 for concentric lay cables.

For large conductors or special conductors it may be lower and each case must be specially considered.

$m_v = m_0 = 1$ for polished wire.
$m_v = .72$ for local corona along cable.
$m_v = .82$ for decided corona along cable.

The three-phase voltage between lines is $\sqrt{3}$ times voltage to neutral; the single-phase voltage between lines 2 times the voltage to neutral. Three-phase conductors assumed in an equilateral triangle.

Sphere gap spark-over:

Effective kilovolts (sine wave).

$e_s = g_s \frac{x}{f}$ both spheres insulated

$e_s = g_s \frac{x}{f_o}$ one sphere grounded,

where

$$g_s = 19.3\,\delta\left(1+\frac{0.54}{\sqrt{\delta R}}\right) \text{ kv/cm.}$$

R = sphere radius cms.

X = spacing between surfaces in cm.

$\frac{X}{R}$	f	f_o
0.1	1.034	1.03
0.5	1.177	1.18
1.0	1.366	1.41
2.0	1.781	1.97
3.0	2.225	2.59
4.0	2.686	3.21
6.0	3.640	
10.0	5.600	
15.0	8.080	
20.0	10.580	

Formulæ [4] may be used for spheres 5 cm. in diameter or larger and for spacings between

$$X = .54\sqrt{R} \qquad \text{and } X = 2R$$

Equations for Calculating Impulse Generator Waves.

Trignometric (Oscillatory) Case: Maximum Voltage:

$$e_{max.} = \frac{2ER}{q}\,\varepsilon^{-\frac{R}{q}\tan^{-1}\frac{q}{R}}\sin\tan^{-1}\frac{q}{R}$$

Where $e_{max.}$ = the maximum of the impulse voltage.

E = the maximum of the 60-cycle voltage across the gap "G" (or the condensers at $t=0$).

R = the resistance of the water tubes.

$$q = \sqrt{\frac{4L}{C} - R^2}$$

$\varepsilon = 2.718$.

[4] For more complete information regarding formulæ see Peek, "Dielectric Phenomena in High Voltage Engineering," McGraw Hill.

Time to Reach a Maximum:

$$t = \frac{2L}{q} \tan^{-1} \frac{q}{R}$$

Voltage at any Time t:

$$e \frac{2E}{\sqrt{\frac{4A}{B^2} - 1}} \varepsilon^{-\frac{BT}{2A}} \sin \frac{Bt}{2A} \sqrt{\frac{4A}{B^2} - 1}$$

Where $A = C \times L$
$B = C \times R$ $\varepsilon = 2.718$.
C expressed in farads.
L expressed in henries.
R expressed in ohms.
t expressed in seconds.

Equations for Calculating Impulse Generator Waves.

Logarithmic (Impulse) Case: Maximum Voltage:

$$e_{max.} = \frac{ER}{S} \left[\left(\frac{R+S}{R-S}\right)^{-\frac{R-S}{2S}} - \left(\frac{R+S}{R-S}\right)^{-\frac{R+S}{2S}} \right]$$

Where e_{max} = the maximum of the impulse voltage.
E = the maximum of the 60-cycle voltage across the gap "G" (or the condensers at $t = 0$).
R = the resistance of the water tubes.

$$S = \sqrt{R^2 - \frac{4L}{C}} .$$

Time to Reach a Maximum:

$$t = \frac{L}{S} \log_\varepsilon \left(\frac{R+S}{R-S}\right)$$

Voltage at any Time t:

$$e = \frac{E}{\sqrt{1 - \frac{4A}{B^2}}} \left[\varepsilon^{-\frac{Bt}{2A}\left(1 - \sqrt{1 - \frac{4A}{B^2}}\right)} - \varepsilon^{-\frac{Bt}{2A}\left(1 + \sqrt{1 - \frac{4A}{B^2}}\right)} \right]$$

Where $A = C \times L$
$B = C \times R$ $\varepsilon = 2.718$.
C expressed in farads.
L expressed in henries.
R expressed in ohms.
t expressed in seconds.

THE EFFECT OF VARIABLE ELECTRON MOBILITIES ON THE FORMATION OF NEGATIVE IONS IN AIR.*

BY

LEONARD B. LOEB, Ph.D.

National Research Fellowship, University of Chicago.

IN 1920 the writer [1] published the results of an attempt to verify the J. J. Thomson [2] theory of negative ion formation, using the mobility curves obtained from the Rutherford alternating current method with a *square wave-form alternation.* At that time nothing was known about the mobility of electrons at higher gas pressures. As a result, only a rough approximation of Thomson's theory was used and the agreement found was but qualitative. In a later paper [3] the writer indicated that in view of the variation of the electron mobility with the electric field, a more precise knowledge of this quantity was required before the theory could be verified.

In December, 1922, it was found that such mobilities could be measured in air below 9 cm. pressure, if certain precautions were taken. The measurement of these quantities appeared to warrant the use of the rigorous application of the J. J. Thomson theory to the Rutherford alternating current method employed by the writer in studying the phenomenon. In his original paper, Professor Thomson [2] indicated how this theory could be applied to this method, but owing to several misprints, the results are not serviceable. The equation deduced here is given in a form originally worked out by Dr. Melvin Mooney, but later modified by the writer to fit the experiments.

The Rutherford method yields the current I received by a plate E of a parallel plate condenser whose plates are d cm. apart when an alternating potential of half period T and amplitude V acts to drive the photo-electrons liberated at the other plate P across to it. By a study of the saturation current I_0 at the pressure p at which I is measured, it is possible to determine

* Communicated by Dr. W. F. G. Swann, Associate Editor of this JOURNAL.

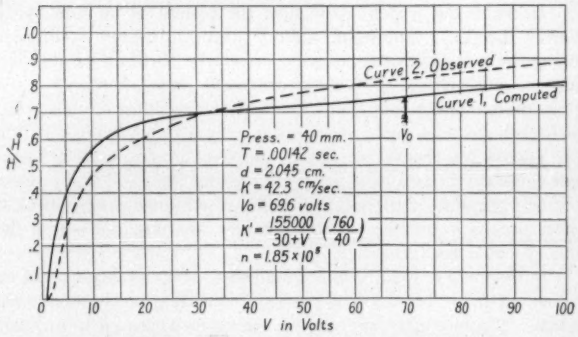
[1] Loeb, L. B., *Phys. Rev.*, N.S. 17, pp. 89–115, Feb., 1921.

[2] Thomson, J. J., *Phil. Mag.*, **30**, pp. 321–338, 1915.

[3] Loeb, L. B., *Phil. Mag.*, **43**, pp. 230–236, Jan., 1922.

the fraction $\frac{I}{I_0}$ of the total possible current between P and E which crosses as a function of V. This current obviously depends on the velocity of the carriers. When an electron, which has a mobility of 20,000 cm./sec., attaches to a molecule and makes an ion of mobility 2 cm./sec., the average velocity of the carrier is chiefly controlled by the distance x which the carrier goes as an

FIG. 1.



electron. Thus the current I is merely a function of the chance that an electron can go a distance x without attaching.

Call dq the quantity of charge received by E in a time interval dt. Then

(1) $dq = I_0\,dt$ if all the carriers liberated during dt can cross. But the carrier which has a composite mobility (part ion of mobility K and part electron of mobility K') can cross only if the time interval t remaining after liberation be defined by

(2) $t \geqq \frac{x}{K'\frac{V}{d}} + \frac{d-x}{K\frac{V}{d}}$ where d is the plate distance and x is

the distance covered as an electron. That is, dq will be $I_0\,dt$ only if the distance covered by the carrier as an electron in the time t of the negative phase remaining is

(3) $$x \geqq \frac{K'}{K'-K}\left(d - \frac{V}{d}tK\right).$$

Now according to J. J. Thomson the chance of an electron going a distance x without attaching is given by

$$W_x = \varepsilon^{-\frac{\omega x d}{nK'\lambda V}} \tag{4}$$

where ω is the velocity of agitation of the electron, λ is its mean free path at the pressure p, K' is its mobility, $\frac{V}{d}$ the field in which it is moving and n the average number of impacts which an electron must make with gas molecules before it succeeds in attaching. This n, according to Thomson, is a constant that depends on the chemical nature of the gas only. Thus the chance of an electron going the necessary distance x to permit the carrier to cross the plates with the time t still remaining after its liberation is

$$W_t = \varepsilon^{-\frac{\omega d}{nK'\lambda V}\left[\frac{K'}{K'-K}\left(d-\frac{V}{d}tK\right)\right]}. \tag{5}$$

Hence for the electrons liberated t seconds before the end of the phase, the quantity of electricity received by E is given by

$$dq = I_o\left(\varepsilon^{-\frac{\omega d}{nK'\lambda V}\left[\frac{K'}{K'-K}\left(d-\frac{V}{dt}tK\right)\right]}\right)dt. \tag{6}$$

Since $K'>>K$, $\frac{K'}{K'-K} = 1$, and if Q be the total current in the time T of the negative phase, then

$$Q = I_o\int_{\frac{d^2}{K'V}}^{T}\varepsilon^{-\frac{\omega}{nK'\lambda}\left(\frac{d^2}{V}-KT\right)}dt. \tag{7}$$

Here the time available for *carriers* to cross extends from $t=\frac{d^2}{K'V}$, the time in which *electrons* themselves can just cross, to the end of the negative phase T. But the quantity Q is experimentally none other than the average current I to the electrometer for the time T, whence

$$\frac{I}{I_o} = \frac{nK'\lambda}{\omega KT}\left[\varepsilon^{-\frac{\omega}{nK'\lambda}\left(\frac{d^2}{V}-KT\right)} - \varepsilon^{-\frac{\omega}{nK'\lambda}\left(\frac{d^2}{V}-\frac{K}{K'}\frac{d^2}{V}\right)}\right]. \tag{8}$$

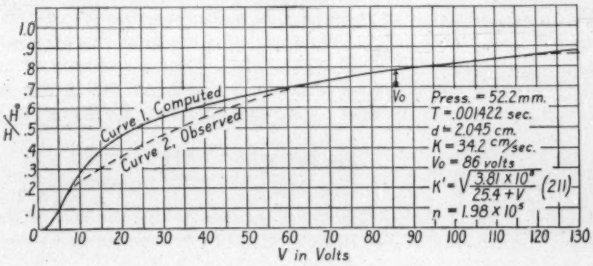
Since $\frac{K}{K'}$ is of the order of magnitude of 10^{-3}, $\frac{K}{K'}\frac{d^2}{V}$ may be

neglected relative to $\frac{d^2}{V}$, and one obtains for $\frac{I}{I_o}$ as a $f(V)$ equation (9)

$$(9) \qquad \frac{I}{I_o} = \frac{nK'\lambda}{T\omega K}\left[\varepsilon^{-\frac{\omega}{nK'\lambda}\left(\frac{d^2}{V}-KT\right)} - \varepsilon^{-\frac{\omega}{nK'\lambda}\left(\frac{d^2}{V}\right)}\right].$$

This equation holds only up to the point $\frac{d^2}{V} = KT$, *i.e.*, to the value

FIG. 2.



of $V = V_0$ for which normal ions of mobility K can cross. At this point (9) becomes

$$(10) \qquad \left(\frac{I}{I_o}\right)_{V_o} = \frac{nK'\lambda}{\omega KT}\left[1 - \varepsilon^{-\frac{\omega}{nK'\lambda}\left(\frac{d^2}{V_o}\right)}\right].$$

Above V_0 the current to E consists of two parts. The first q_1 is due to ions of mobility K which cross in full numbers and yield a current I_0 for a time interval extending from the time at which they can just cross with a field V, *i.e.*, $t = \frac{d^2}{KV}$, to the time $t = T$. The second portion, q_2, is due to the carriers which start as electrons and therefore cross in the time interval from $t = \frac{d^2}{K'V}$, which an electron requires to cross, to the time $t = \frac{d^2}{KV}$ when the ion can cross. Thus above $V = \frac{d^2}{KT}$, the quantity Q is represented by

$$(11) \qquad Q = q_1 + q_2 = I_o\int_{\frac{d^2}{KV}}^{T} dt + \int_{\frac{d^2}{K'V}}^{\frac{d^2}{KV}} \varepsilon^{-\frac{\omega}{nK'\lambda}\left(\frac{d^2}{V}-KT\right)} dt.$$

Again neglecting $\frac{K}{K'}\left(\frac{d^2}{V}\right)$ relative to $\frac{d^2}{V}$, one obtains,

(12) $$\frac{I}{I_o} = \left(1 - \frac{d^2}{VKT}\right) + \frac{nK'\lambda}{\omega KT}\left[1 - \varepsilon^{-\frac{\omega d^2}{nK'\lambda V}}\right]$$

whence setting $V_0 = \frac{d^2}{KT}$, 12 becomes

(13) $$\frac{I}{I_o} = \left(\frac{V - V_o}{V}\right) + \frac{nK'\lambda}{\omega KT}\left[1 - \varepsilon^{-\frac{\omega d^2}{nK'\lambda V}}\right].$$

This approaches $\frac{I}{I_o} = \frac{V - V_o}{V}$ for values of T that are large, which it should do as this equation has been observed to hold for ions at low frequencies.

As was shown by the writer in a previous paper,[3] neither λ nor ω is known for electrons. But these quantities are closely related to the electron mobility K' in the equation given for electron mobility by Townsend,[4] *viz.*, $K' = .815\ \frac{e}{m}\frac{\lambda}{\omega}$, where e is the electron and m its mass. Hence putting $\left(\frac{m}{.815e}\right) K'$ for $\frac{\lambda}{\omega}$, and multiplying the result by 300 as the equations 9, 10 and 13 are in volts, while e is in electrostatic units, the equations 9, 10 and 13 become open to experimental verification in the forms,

(14) Below V_0,

$$\frac{I}{I_o} = \frac{6.8 \times 10^{-16} n (K')^2}{KT}\left[\varepsilon^{-\frac{1.47 \times 10^{15}}{n(K')^2}\left(\frac{d^2}{V} - KT\right)} - \varepsilon^{-\frac{1.47 \times 10^{15}}{n(K')^2}\left(\frac{d^2}{V}\right)}\right].$$

(15) At V_0,

$$\frac{I}{I_o} = \frac{6.8 \times 10^{-16} n (K')^2}{KT}\left[1 - \varepsilon^{-\frac{1.47 \times 10^{15}}{n(K')^2}\left(\frac{d^2}{V} - KT\right)}\right].$$

(16) Above V_0,

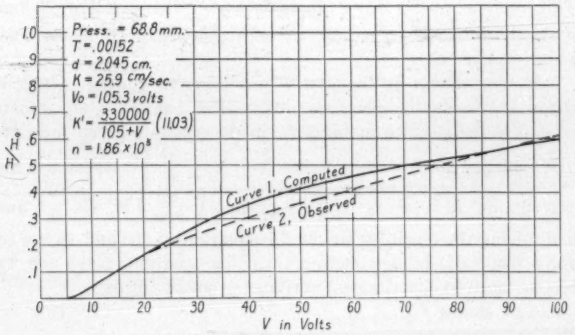
$$\frac{I}{I_o} = \frac{V - V_o}{V} + \frac{6.8 \times 10^{-16} n (K')^2}{KT}\left[1 - \varepsilon^{-\frac{1.47 \times 10^{15}}{n(K')^2}\left(\frac{d^2}{V}\right)}\right].$$

Here V_0 is the critical potential at which *ions* can just cross at a pressure p, and K' and K are the electronic and ionic mobilities at this pressure.

[4] Townsend, J. S., "Electricity in Gases," Oxford, 1914.

In order to compare the observed mobility curves with the computed ones, n must be determined. This is done for each curve at a given pressure by substituting the value of $\frac{I}{I_0}$ found at the voltage V_0, together with K, K', T and d into equation (15). This then gives the value of n characteristic of each pressure. With this value of n, a curve of $\frac{I}{I_0}$ as a $f(V)$ may be computed for the values of K, T, d and p used in the experiments once K'

FIG. 3.



is known as a $f(V)$. This procedure virtually consists in giving the observed and computed mobility curves one common point at V_0.

The values of K' used in December, 1922, were determined for pressures of 41, 52, 66, and 92 mm., using a plate distance d of 1.955 cm. They were then summarized by the following four equations:

(1) $p = 41$ mm. $K' = \frac{155{,}000}{30 + V}\left(\frac{760}{41}\right)$

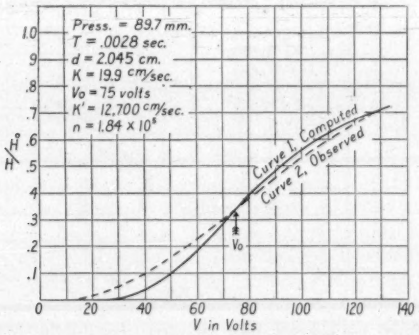
(2) $p = 51.5$ mm. $K' = \sqrt{\frac{3.81 \times 10^8}{25.4 + V}}\left(\frac{760}{51.5}\right)$

(3) $p = 66$ mm. $K' = \frac{330{,}000}{105 + V}\left(\frac{760}{66}\right)$

(4) $p = 92$ mm. $K' = 1500\left(\frac{760}{92}\right)$

A full description of the apparatus and method used in obtaining the mobility curves is given in the writer's first paper [1] on the subject. The ion mobility curves were determined for nearly the same pressures with as nearly as possible the same plate distance, and with air that had been dried in the same manner as that used for the electron mobility measurements. The results of these measurements yielded the $\frac{I}{I_0}$ curves plotted as curves 2, Figs. 1, 2, 3, 4, and 5. The $\frac{I}{I_0}$ curves computed from the theory given are shown as the curves numbered 1 in the same figures.

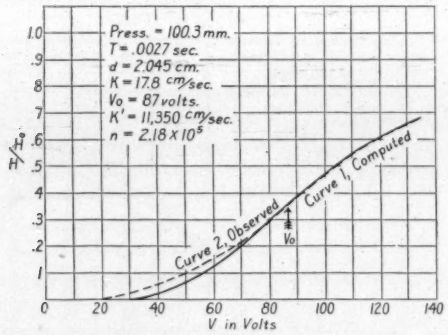
FIG. 4.



It is at once seen that even though there are some deviations between the two sets of curves, the general agreement is striking considering the uncertainties in the values of the electron mobilities used. The n's computed from the points at V_0 for different pressures have the values 1.85×10^5, 1.98×10^5, 2.2×10^5, 1.86×10^5, 1.84×10^5 and 2.18×10^5 at pressures of 40, 52.2, 60.2, 68.8, 89.7 and 100.7 mm., respectively, which are quite consistent and very constant compared with the values found in 1921. In some cases where the deviations between the curves occur, they may be due to errors in the $\frac{I}{I_0}$ measurements. In those cases where the observed curves lie above the computed ones at higher voltages, the error doubtless lies in disturbances due to a slight dielectric absorption in the insulators. This becomes serious when the positive fields are markedly greater than the negative fields in the

A.C. The employment of such fields is necessary to reduce space charge effects. The slower rise of the observed curves at lower pressures compared with those theoretically expected is perhaps in part due to the fact that the field across the plates fell slightly during an alternation because of electrical leakage while the brush passed over the insulating portion of the commutator. A measurement of the leakage resistance indicated that this was 10^9 ohms while the capacity was estimated to be about 500 cm.,

FIG. 5.



which seemed to indicate that an error due to the leakage was negligible. Measurements made later showed that by increasing the capacity of the alternating circuit to .01 microfarad, the initial rise of the observed curve became markedly sharper. Unfortunately, these measurements were impaired by other disturbing factors, and further data could not be taken owing to the writer discontinuing the work before leaving Chicago. The greater prominence of the feet of the curves observed at lower fields near pressures of 90 cm. is probably due to the fact that here the value of K' is not constant as assumed, but decreased very slightly with increasing V.

One might accordingly conclude that the theory has been very successfully confirmed, and this apparent confirmation was the basis of an abstract (No. 48) published in the *Phys. Rev.* in March, 1923. With a view to obtaining a closer agreement than the foregoing, the writer extended the electron mobility measure-

ments in air considerably during 1923. In the course of extending them, it became obvious that certain corrections previously ignored had to be made on the values used above. The results of these investigations are being published [5] in a forthcoming paper and may be summarized by the following equations:

(1) $p = 41$ mm. $K' = \frac{67{,}500}{5.0 + V}\left(\frac{760}{41}\right)$

(2) $p = 51.5$ mm. $K' = \frac{130{,}400}{22.1 + V}\left(\frac{760}{51.5}\right)$

(3) $p = 60$ mm. $K' = \frac{155{,}00}{36.3 + V}\left(\frac{760}{60}\right)$

(4) $p = 66$ mm. $K' = (3074 - 19.55\,V)\left(\frac{760}{66}\right)$

(5) $p = 92$ mm. $K' = (3074 - 19.55\,V)\left(\frac{760}{92}\right)$

These results in air are uncertain and irregular compared with the electron mobilities found for other gases. Their accuracy might well be questioned on the ground that some of the assumptions made in deducing the corrections may not be experimentally fulfilled; notably, the one assuming the reduction of the fields due to space charge effects to negligible values. If this assumption were incorrect, the mobilities would be found to have been overcorrected. If the correction had been omitted, it would make the mobilities conform to the older values. However, the last values given are *logically* the more correct results and, until proven otherwise, constitute our only knowledge of the values of these quantities.

If the new values of K' be placed into the equations above, the whole agreement disappears. Thus, while in general the evolution of the computed $\frac{I}{I_o}$ curves, as a function of pressure, resembles the observed curves, the two differ so markedly as to make any agreement impossible. Curves showing the type of disagreement obtained are indicated by the curves 1 and 2 of groups A and B, Fig. 6, for pressures of 40 mm. and 89.7 mm.

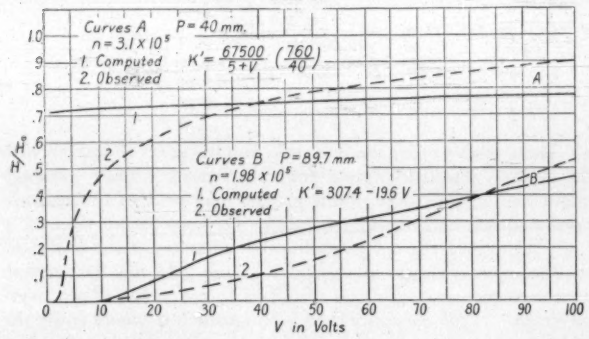
It therefore appears at present to be impossible to draw any definite conclusions from the results. If the corrected electron mobility values lately deduced for air are the true ones, the Thomson theory obviously does not hold in its original form. If n were not a constant, but increased as V increased, the curves might be made to agree again. This would mean that attachment

[5] Loeb, L. B., *Proc. Nat. Acad. Sciences*, 1923.

is a function of ω and that n increases as ω increases. But in this case the change of n as a $f(\omega)$ would vary widely with the pressure. A variation of n with ω is claimed to exist by Bailey,[6] who criticizes the writer's earlier results on this basis.[7]

On the other hand, the agreement of the mobility curves computed from the uncorrected electron mobilities with the observed curves is so striking that the writer seems loth to discard this

FIG. 6.



evidence. This attitude seems somewhat justified in view of the fact that the uncertainties produced by the space charge effects assumed negligible would, if the effects were not negligible, yield mobilities which would again give good agreement. At this juncture, one is accordingly free to adopt whichever view one inclines to on the basis of other data.

In its broad outline, the theory of ion formation of J. J. Thomson must be accepted. That is that ion formation at first consists of the attachment of an electron to a neutral molecule or atom, and that in general this attachment is a chance occurrence, the average number of impacts required for it being primarily a function of the chemical nature of the atom or molecule. If for

[6] Bailey, V. A., *Phil. Mag.*, **46**, pp. 213–218, July, 1923.

[7] The criticism mentioned is partially incorrect, as the writer did not use a sine wave form in this work, but worked with a square wave. Otherwise, the possible assumption of an n variable with the velocity *for low values of* ω is permissible, though Bailey gives no experimental data to verify his statement by. For higher fields and hence for higher values of ω, Wahlin[8] has shown that n is not a very marked function of V.

lower velocities n is a function of the speed, it does not invalidate the general viewpoint, though it doubtless will modify the mathematical treatment in some details. For in order of magnitude alone, the attachment constant n is such a unique function of the chemical nature of the gas that the smaller deviations from constancy may be neglected. For He, A, N_2, H_2, and CO, Franck,[8] Wahlin,[9] Townsend and his pupils,[6] and the writer have shown n to be practically infinite. While for C_2H_6, C_2H_4, C_2H_2, CO_2, N_2O, C_2H_5Cl, O_2 and Cl_2, Wahlin [9] and the writer [2] have shown that n varies from 10^7 to less than 10^3.

As to the nature of the attachment process, little can be said. It is certainly not due to the electron acquiring a certain threshold energy from the field as Wellisch [10] postulated. It might depend somewhat on the electron having a low enough speed so that it could be captured by a molecule as postulated by Bailey. In no case can n be measured in unmodified gases. Either ultra-violet light or alpha particles act on the gas through which electrons travel. Thus the n may be a characteristic of the "activated" state of the molecules produced by these agents. An extreme stage of an activated molecule would be one that is dissociated. It is known that the electronegative *atoms* have very high electron affinities. Thus the high values of n could be due to the probability of the electron meeting an atom. This would perhaps seem unlikely in the case of Cl_2 where n is small. An hypothesis of this nature would seem to explain the "ageing" effect on positive ions observed by Erikson [11] and Wahlin,[12] as well as the difference in mobility between positive and negative ions. If ionization involves dissociation of the molecule, then the positive ion starts as a positive atom ion. As time goes on, it can attach to another neutral atom. In doing this its mass will increase, its free path decrease, and consequently its mobility will decrease with time as found by the aforementioned observers. The negative electron will remain free until it finds an atom. To this it will attach to form a negative ion. This will stay an atom ion, and the negative ion will thus retain its initial mobility. This mobility is the same as that of the positive ion before it adds on its second atom.

[8] Franck, J., *Verh. Deutsch. Phys. Ges.*, **12**, p. 613, 1910.
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On a Simple Method of Extending the Bolmer Series of Hydrogen in a Vacuum Tube. R. WHIDDINGTON. (*Phil. Mag.*, Oct., 1923.)—In an ordinary vacuum tube it is difficult to get more than four lines of the primary spectrum of hydrogen. In contrast to this is the completeness of the series in starlight. By using a hot tungsten cathode in hydrogen at a pressure of about .001 mm. of mercury, at least nineteen members of the series were obtained.

G. F. S.

The Scattering of Light by Liquid Droplets and the Theory of Coronas, Glories and Iridescent Clouds. BIDHUBHUSAN RAY. (*Proc. Indian Asso. Cultiv. Sci.*, **8**, Pt. I, 1923.)—In certain fields of science the investigator can carry on his work far from the maddening crowd and in lake and stream under the open sky. Such experiences are rather rare in physics though by no means unknown. The magnetic survey of the earth conducted by L. A. Bauer, the phenomena discussed in Humphreys' "Physics of the Air," in Arrhenius' "Cosmic Physics," and in the brochure of Freiherr von und zu Aufsess on "Die Physikalischen Eigenschaften der Seen," all these have taken the physicist away from his laboratory and have made of him for the time a passive observer of what he cannot control and manipulate. So it is with the subject of this paper.

"G. C. Simpson has advanced the very interesting theory that the iridescent borders and irregular patches of colour occasionally shown by thin high clouds some 15° or 30° from the sun or more are only fragments of coronas formed by exceedingly small undercooled droplets of very approximately uniform size." To test this clouds were formed in a flask by the adiabatic expansion of air saturated with water vapor. The largest drops had a radius of about .008 mm. and the smallest of .0015 mm. The light from a 1000 c.p. tungsten lamp was focussed upon the centre of the flask. "If observations are made in a direction nearly parallel to the direction of light, the eye being placed on the side opposite to that at which the source of light is situated, one can see vivid patches of colour in the track of the beam, red and green being the most prominent tints. If the droplets are large, these coloured patches can only be seen in directions embraced within a small solid angle, but as the size decreases, they become visible at larger and larger angles. With very thin clouds consisting of small droplets, the coloured patches could be seen even at a large angle (30° to 40°). The observations thus lend an experimental support to Simpson's suggestion about the formation of the iridescent clouds."

From the results of additional experiments, the author is led to reject Humphreys' explanation of glories as akin to coronas, the scattered light being that reflected from the deeper parts of the cloud on which the phenomenon is seen. The effect is ascribed to the scattering of sunlight at the surface of the cloud.

This paper is a manifestation of the interest felt in British India in the Tyndall Effect and kindred optical phenomena. G. F. S.

IMPACT EFFECTS IN NITROGEN AND NITRIC OXIDE.*

BY

C. B. BAZZONI and A. T. WALDIE.

THE study of ionization potentials and of resonance potentials ought to give the most direct evidence on the structural constants of atoms and of molecules and that most free from theoretical qualifications. An analysis shows, however, that we can interpret with certainty but a small percentage of the numerous data at present available.

A good concordance between theory and observation exists for metallic vapors. With reference to gases, the results for helium, which is monatomic, are most definite but are of disputed significance. When we come to polyatomic molecules the multiple ionization steps observed in the simplest molecular gases can be related to ionizations of the atoms or of the molecules in various ways although none of the relations carry conviction. With complex molecules involving radicals of different elements the different modes of ionization which are possible allow the prediction of numerous critical potentials, the verification of any of which by experiment may be accidental.

In dealing with a gas which is not entirely inert, and it is questionable whether any gas is entirely inert under the usual experimental conditions, the atomic forces introduced by the electrodes, by the hot filament and by the sensitizing or catalyzing action of the walls of the containing vessel and of the films of gas or metal thereon adsorbed, must be taken into consideration. The atoms or molecules introduced may be changed into forms of altered stability by the absorption of radiation either due to electronic impacts on other atoms or emitted from the hot cathode, by the absorption of energy through contact with other stimulated units, by direct impact of electrons on them or by catalysis. Dissociation of the molecules is one of the effects which may be produced by these agencies. Between these altered and perhaps sensitized units, chemical reactions may take place with each other or with the metal parts or with gases adsorbed on the walls. It is

* Communicated by Professor Bazzoni. Contribution from the Randal Morgan Laboratory, University of Pennsylvania.

therefore difficult to specify the constitution of the complexes which may exist in the device at any given time. These complications lead to obvious difficulties in interpreting experimentally obtained energy measurements.

The difficulties of interpretation extend also to considerations of theory since the redistribution of energy among the various degrees of freedom of molecular complexes, when disturbed by impact or otherwise, is difficult to follow. The energy transferred may reappear as energy of rotation of the system about its centre of gravity, as energy of oscillation of the parts of the system relative to one another or as kinetic energy of displaced electrons; or it may be distributed in any way among these various modes of motion. If we consider these types of energy all to be quantized and suppose the frequencies radiated while the molecule is returning to its normal state to be given by $h\nu = W_2 - W_1$ for each disturbed mode, it is apparent that a complex radiation ought to be expected instead of the single lines developed from individual Bohr atoms. These considerations strengthen the notion long held and now regarded as certain that the band spectra are built up of characteristic radiations from molecules just as line spectra are built up of characteristic radiations from atoms. These developments have been extensively studied on the mathematical side by Schwarzchild, Heurlinger and Lenz and others but the experimental evidence which has been collected connecting band emission with excitation potentials is extremely meagre.

The difficulties above referred to have led physicists generally to avoid the study of complex or chemically active gases by impact methods. It is nevertheless to be expected that such studies will give much information on the nature of chemical reactions of the simpler type. This paper constitutes a report on certain work along these lines carried out with nitric oxide and nitrogen.

The first experiments were made in a three-electrode tube with nickel grid and plate coaxial on a straight tungsten filament of seven mil wire. The radius of the plate was five millimetres, its height one centimetre. The grid was placed one millimetre from the filament. The plate was set horizontally to facilitate spectroscopic observations. Connections were made in the usual way so that ionization and resonance points could be determined from total current curves using the arrangement as a two-electrode device or from partial current curves run with a

retarding potential on the plate. The experimental tube had an upper chamber with a quartz window so that the contained gas could be irradiated with light from a quartz mercury lamp and was protected by a trap on which ice-NH_4NO_3 mixture, carbon dioxide snow in acetone or liquid air could be used as desired. Beyond the trap, connection was made to a Shrader optical lever manometer and also to a rapid McLeod gauge. The apparatus was provided with the minimum number of stopcocks necessary to control the gas. An induction furnace was available, the coil of which could be slipped over the experimental tube. With this in place the metal parts could within a few seconds be raised to a red or white heat and so held as long as desired. Exhaustion was carried out with a mercury diffusion pump.

A second apparatus was also used in which a spiral nickel grid was placed nine millimetres from a spiral tungsten cathode and surrounded by a nickel plate of ten millimetres radius.

The nitric oxide was prepared from electrolytic copper and c.p. nitric acid. It was washed through distilled water and dried with concentrated sulphuric acid and stored in a bulb of the main apparatus from which it could be admitted to the experimental chamber as desired. A fresh supply was made each day.

In NO we have a compound which, although stable under ordinary conditions, is readily changed into other oxides. Its boiling point is $-153°$ C. and its melting point is $-167°$ C. so that it is easily frozen out by liquid air. It has a negative heat of reaction, 21.6 kg. cal. being absorbed on the formation of a gram molecule. If the normal molecule be subjected to simple electron impact we might expect any of the following reactions to ensue: (1) Dissociation into N and O followed by ionization of either the N or O or both, (2) dissociation into N_2 and O_2 followed by ionization of N_2 or O_2 or both or by dissociation of either or both of these molecules followed by ionization of either or both of the atoms, (3) ionization of the molecule with the formation of plus charged NO and electrons. The second of these possibilities seems the most probable. We in this case begin with NO molecules and end with electrons and plus ions of N and O. If sufficient data were available we could possibly determine the total energy required to bring about this transformation at one blow by finding the sum of the heat of dissociation of nitric oxide, expressed in volts, the heats of dissociation of N_2 and of O_2

and the ionization potentials of N and of O. This transformation at one blow could hardly be produced, however, in an experimental tube since on gradually raising the potential the effects ought to occur successively and, depending on conditions of pressure and bombardment intensity, one of the constituent effects would be emphasized at the expense of the others. The dissociation energy of N_2 and of O_2 being unknown it is not possible to make this calculation. Furthermore, as pointed out above, the conditions for simple electron impacts seldom exist in experimental tubes containing active gases. In addition to the impact effects we must consider radiation reactions and the catalytic effect of metal and other surfaces, as well as the ordinary chemical reactions which may take place between the gas and the materials in the tube. What actually occurs is determined by the interaction of all these factors.

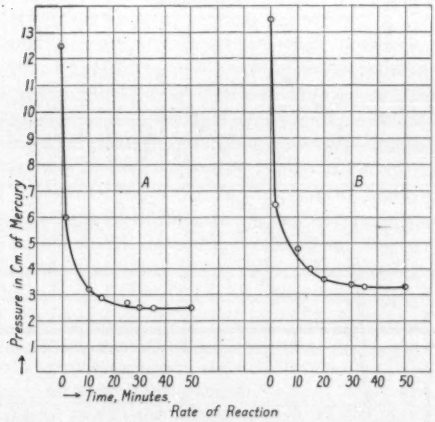
In the first place the results of Bertholet[1] would lead one to expect that NO might dissociate or otherwise break down from the action of the ultra-violet light from the filament. Tests on this point were made using a quartz lamp from which radiation as low as 2000 Å. could be detected in the fluorescent eyepiece of a spectrometer. The light from this lamp was admitted to the experimental device through a quartz window, the tube of the lamp being within one centimetre of the window which was cooled with water. Hulburt[2] states that very little radiation with a wave-length less than 3000 Å. is emitted from a tungsten filament even at the highest workable temperatures, and it is therefore probably safe to conclude that no effects will be produced by tungsten radiation as great as those produced by the radiation from the quartz lamp.

The equation $2\ NO = N_2 + O_2$ shows that dissociation is not signalized by a pressure change. On the other hand any reaction resulting in the formation of a solid oxide or nitride will be evidenced by an immediate pressure decrease. Dissociation can, however, be detected by the use of liquid oxygen which freezes out NO but not N_2 or O_2. Using this method tests were made with pressures ranging from 0.1 mm. to 10 cm. and with exposures to the light up to one hour without any evidence whatever of dissociation or other chemical action. The gas was frozen down as a flocculent white solid before the exposure and again afterward

with identical reductions in pressure. It is to be remarked without explanation that the gas used as pure NO was invariably reduced in pressure almost exactly 80 per cent. on freezing, indicating the presence of a constant percentage of non-condensible gas.

Bertholet obtained a definite decomposition under somewhat similar conditions with a reduction in pressure due to fixation of a large part of the oxygen and some of the nitrogen. However his NO was at atmospheric pressure. It seems from these and

FIG. 1.



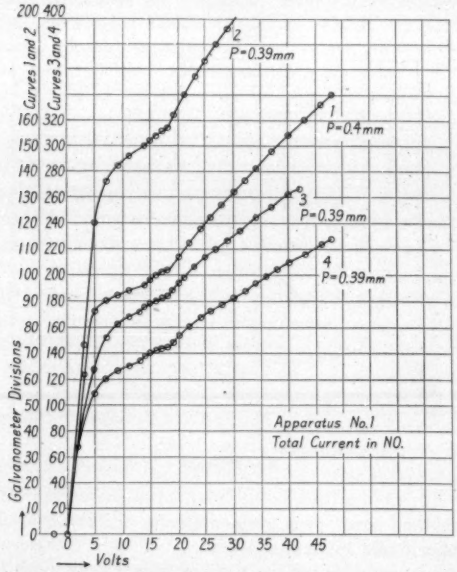
numerous other observations that photochemical actions are stimulated in rarefied gases with great difficulty becoming notable only at atmospheric and higher pressures.

The same negative results were obtained both with the lamp cooled by an air blast and with it running at a dull red heat. With the hot lamp the thermal radiation was very strong. We may conclude from these results that neither thermal nor ultra-violet radiation above $\lambda 2000$ will break down the rarefied NO used in the device in the course of the experiments described below. It is a much more difficult matter to decide on the exact effects to be ascribed to catalyzers which may be present in the tube.

There are no ordinary chemical reactions between NO and

nickel, the material of the electrodes, at low temperatures and pressures. To test the effects at high temperatures the tube was filled with NO at pressures ranging from .01 mm. to 10 cm. and the plate and grid raised to a red heat by means of the induction furnace. There resulted in all cases an immediate pressure decrease, the rate of decrease being indicated in Fig. 1. The

FIG. 2.



pressure could be reduced roughly to one-half by repeated heatings of the electrodes during which they became coated with a yellowish-green or apple-green deposit. Analysis supported the obvious deduction that this deposit was nickel oxide (NiO). Similar pressure changes were induced by glowing the filament but more slowly. In this reaction we may assume that those molecules which come into contact with the hot metal are broken down, the dissociation and the recombination of the oxygen with

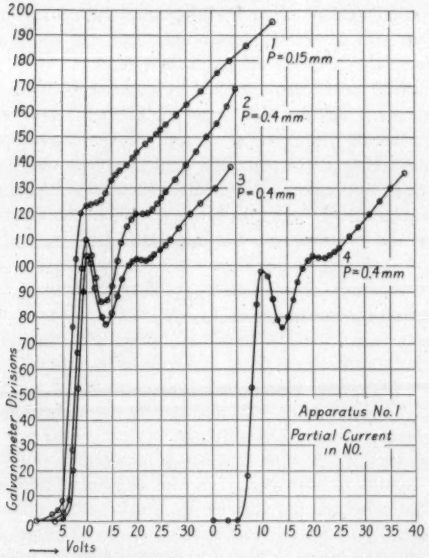
the metal being practically simultaneous. The velocity of the reaction depends on the size of the heated surface and on the pressure. It is apparent from these facts that in the ordinary use of a hot cathode device for impact measurements in NO, the NO molecules must quickly disappear leaving an atmosphere of nitrogen. However, the area of the filament being small and the volume of the device relatively large it takes several minutes for this action to become sensibly complete. Subsequent tests indicate that the residual N in the neighborhood of the filament is atomic but that it readily recombines into the molecular form especially in the presence of oxidized metals.

Certain of the results obtained in impact measurements using apparatus No. 1 (grid 1 mm. from the filament) are summarized in Fig. 2 which shows total current curves, *i.e.*, curves from electrons arriving at the plate and grid used as a single electrode. These curves were taken in immediate succession in the same gas, the pressures during each run being shown in the figure. Prior to taking the observations the apparatus had been thoroughly cleaned by glowing all the electrodes and heating the glass in a very high vacuum. These curves are characterized by two break points indicating ionization at 14 volts (uncorrected) and at 18 volts (uncorrected). The break at 14 becomes successively less marked in the successive curves and falls back somewhat in curves 3 and 4. Accepting Boucher's[3] measurement of the ionization potential of oxygen as 14 volts and setting the ionization potential of nitrogen close to 17 volts (Brandt,[4] 17.75; Foote and Mohler,[5] 17.1; Boucher,[3] 15.87) the first break is probably due to oxygen and the second to nitrogen. As the oxygen is eliminated by combination with the hot cathode its break becomes less evident. If this identification is correct the NO molecules have been dissociated at some lower voltage by electron impact or by the hot filament since the tests cited above indicate that it is improbable that they were dissociated except at the surface of the cathode by radiation or heat in the absence of the field.

Partial current curves were then taken to locate inelastic impacts at lower potentials. In these runs the electrons were accelerated to the grid in a gas pressure such that the grid distance was of the same order as the mean free path; a back potential, usually of 4 volts, was kept on the plate and the electron current

arriving at the plate measured. The photoelectric current from the plate gave no difficulty since it was of a lower order of magnitude. The results are shown in Fig. 3. These curves were run in rapid succession. The gas was fresh for curve 1. The pressure was increased with fresh gas for curve 2. Curves 3 and 4 are repeats of 2. They show the development of an inelastic

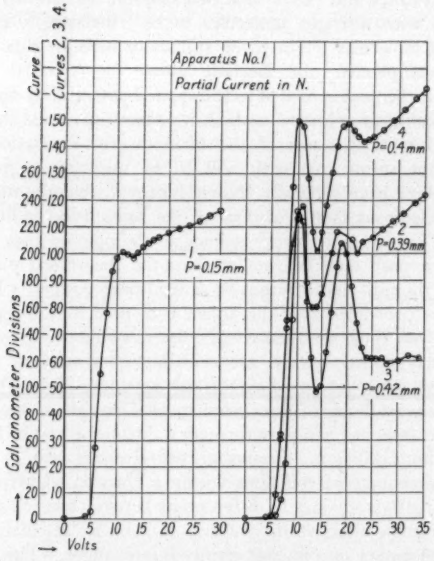
FIG. 3.



impact at 10 volts (uncorrected) and at 18 volts (uncorrected). Correcting in the usual way we have here evidence of inelastic collisions close to 8 volts. Accepting Foote and Mohler's[5] value of the first inelastic impact in oxygen as 7.9 volts and in nitrogen as 8.18 volts and Boucher's [3] corresponding values of 8.0 and 8.4, the bump observed might be due either to nitrogen or to oxygen or to both. In order to differentiate these effects if possible, similar curves were made with pure nitrogen prepared from com-

mercial nitrogen by passing it over hot copper, lime and carbon dioxide snow. Of the curves obtained shown in Fig. 4, 1, 2 and 3 are seen to be essentially identical with 1, 2 and 3 of Fig. 3. Curve 4 of Fig. 4 was made with nitrogen which had been bubbled through water so that it was loaded with water vapor. It seems impossible to differentiate the residual gas of NO from pure

FIG. 4.



nitrogen by this test. This is doubtless to be expected since the first resonance points of oxygen and nitrogen are so nearly the same. There is no definite evidence here of inelastic impacts in NO between 4 volts and 8 volts. The range below 4 volts was not studied. The dissociation energy of NO might be guessed to be lower than that of hydrogen which is fairly well established close to four volts.

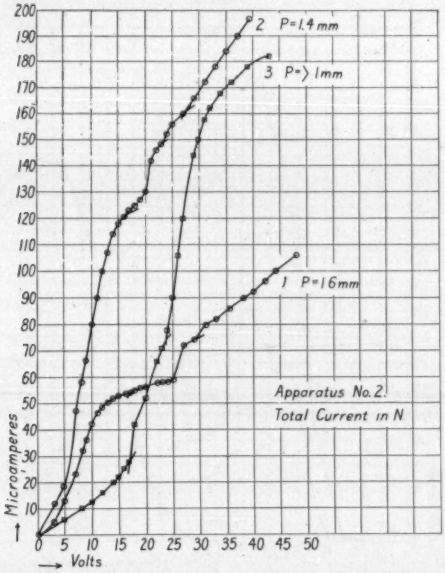
These curves enable us to say with a degree of certainty that NO in a hot filament device of the type here used is broken down

by the hot filament into nitrogen and oxygen, the oxygen being eliminated progressively in the form of tungsten oxide and that the critical impact potentials are during the first few minutes those associated with both oxygen and nitrogen but finally are the same as those developed in pure nitrogen.

Apparatus No. 2 was constructed with a large grid-filament separation—9 mm. filament to grid, 2 mm. grid to plate. The work of Franck and Hertz[6] and of Compton[7] has shown electron collisions with nitrogen molecules to be "inelastic"—collisions with NO molecules ought to be still more inelastic due to their greater complexity. In inelastic gases the velocity actually attained at the grid is related to the applied potential by an expression involving an unknown coefficient of restitution and the effects developed in such gases if the filament-grid separation much exceeds the mean free path will be of uncertain significance. Observations have generally shown, however, that the mean free path of electrons is not always of the magnitude indicated by theory. Franck and Hertz[6] inclined to the opinion that the true mean free path may be smaller than the theoretical one while Partzch[8] thought that it might be several times longer. Recently Loeb[9] has concluded that the actual free path in nitrogen must be about four times the theoretical. Impact effects corresponding to the full applied voltage are certainly obtainable in inelastic gases with grid-filament distances ten or more times the mean free path even though theory predicts that less than one electron out of one hundred will pass through a distance equal to five free paths without collision. Conversely other results seem to indicate a large percentage of collisions within a fraction of a free path. It is apparently necessary to differentiate between the cross-section of the molecule effective in viscosity and similar calculations and that which enters into impact energy interchanges. The number of effective collisions per unit path may be less for high-speed electrons, which shoot through the exterior zones of molecules with little deviation, than for very slow ones thus leading to an abnormally great apparent free path for rapid electrons. The effective or virtual free path, that is the distance over which the electron may travel without any considerable deviation or loss of energy, would thus be a function of its directed speed and greater than the free path calculated from the kinetic theory. It is well known that this is actually the case for very high-speed particles

like beta rays. Again, the degree of inelasticity of the impact may very well depend on the time the electron remains in the zone of influence of the molecule so that low velocity collisions may be more inelastic than high velocity ones. Karrer's[10] investigation of the nature of collisions in nitrogen led him to the guarded statement that the collisions were inelastic if the velocity was

FIG. 5.

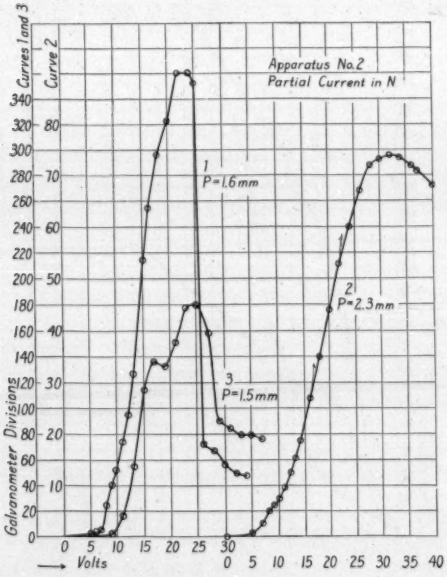


below that corresponding to the resonance potential and if the number of collisions per second was not too great. These considerations give the curves of Fig. 5 and Fig. 6 some significance.

The total current curves for nitrogen (Fig. 5) show ionization at 17, 24 and 28 volts (uncorrected) with a pressure such that about 36 mean free paths were comprised in the accelerating distance. These critical values are nearly the same as those obtained by Brandt,[4] 17.75, 25.4 and 30.7 (corrected), who remarks

that the points are independent of pressure but are more marked at higher pressures. A curve taken in our apparatus at a lower pressure (No. 3—Fig. 5) shows the higher voltage breaks to be absent or much reduced. These curves indicate that the virtual free path of a considerable number of the electrons is 20 to 30 times the mean path predicted by the kinetic theory. It is further-

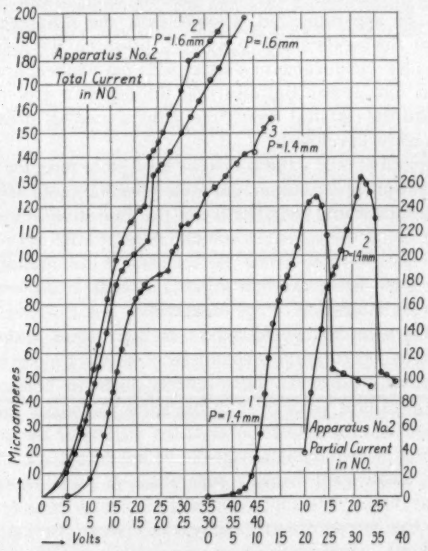
FIG. 6.



more evident that the 24-volt ionization point is the most important one under the conditions of the experiment. Reference to the partial current curves for nitrogen in this apparatus (Fig. 6) shows that inelastic impacts occur in the neighborhood of 8, 16 and 22 volts (uncorrected) even with an accelerating distance of 50 mean free paths as in curve 2. A considerable number of electrons, although by no means the greater number, must fall freely to the grid at each applied voltage. The higher inelastic

impacts seem to correspond to the ionization points of the total current curves rather than to multiple values of the first resonance potential. It is again seen that the most important ionization point is around 24 volts, the heavy drop at this point being probably due to the arrival of numerous plus ions at the plate rather than to the stoppage of the electron stream. The presence of the

FIG. 7.



8-volt break seems to preclude the possibility of shifting the whole curve to the left to make the apparent 22-volt break correspond to the usual first ionization point near 17 volts. Such a shift would otherwise be justified on the assumption of a certain value, nearly 1.0, for the coefficient of restitution.

The NO curves obtained with apparatus 2 are collected in Fig. 7. These curves differ from those of nitrogen in the same apparatus in two respects: First, in the partial current curves the 8-volt inelastic impact is less marked, and, second, in the total current curves the 17-volt ionization point is less definite. Critical

comparison of these curves, for example, 3 of Fig. 7 with 1 of Fig. 5 and 1 (Partial) of Fig. 7 with 1 of Fig. 6, shows, however, that here again it is impossible to distinguish between the residual gas from NO and pure nitrogen in the same apparatus.

The marked difference in the form of the corresponding curves from the two devices evidenced by a comparison of Fig. 6 and Fig. 7 (Partials) with Fig. 3 is probably connected with the difference in pressure, which was 0.4 mm. in apparatus No. 1 and 1.6 mm. in apparatus No. 2, and with the difference in the lengths of the accelerating paths. If, however, we assume that the molecules which come in contact with the filament are dissociated by it into atoms and also that the effective free paths are longer than the classical mean free paths somewhat broader conclusions can be developed.

In apparatus No. 1 the collisions take place near the filament in the atmosphere of atomic gas—the appearance of the 17-volt ionization thus would be indicative of the ionization of atoms. In apparatus No. 2 the collisions corresponding to the recorded voltage take place remote from the filament in an atmosphere of molecular gas—hence the first important break at 24 volts would be due to the ionization of the molecules.

On this view we would expect in any device with a large grid-filament separation a preponderance of effects due to gas in the molecular condition. These effects ought to be accentuated at higher pressures since at high pressures the movement of the atoms formed at the filament over to the vicinity of the grid without collision or recombination would be less likely. Even with a relatively small grid-filament separation a pressure could be reached at which the molecular effects would become notable provided the pressure were not great enough to cut off the electron flow.

The conclusions then suggested are that the 8-volt inelastic collision corresponds to the first resonance point of the nitrogen atom —that the ionization of the atom takes place at 17 volts while 24-volt energy is necessary to ionize the molecule at one blow, comprising the energy to separate the atoms and to ionize one of them at one collision. The exact concordance between the 8.2-volt resonance and the Lyman doublet at λ1492.8 and λ1494.8 in the line spectrum is additional evidence that this resonance point belongs to the atom. In this same connection the appearance of

the positive bands at 7 volts as observed by Foote and Mohler [11] indicates some sort of molecular disturbance at that voltage, perhaps dissociation. The same observers localized the appearance of the negative bands at 21.5 volts (fully developed at 25 volts) perhaps corresponding to the 24-volt ionization. Twenty-four is, of course, 17 plus 7, the ionization energy of the atom plus the suggested dissociation energy of the molecule, but this relation is not necessarily significant. The attempts made with the apparatus here described to connect the observed critical potentials with the development of spectra were unsuccessful.

The results of the experiments described above may be summarized as follows: It is shown that NO at low pressures is not broken down by ultra-violet light or by heat radiation but that hot metals produce a dissociation and subsequent elimination of the oxygen leaving, essentially, nitrogen. This dissociation and the progressive elimination of the oxygen are clearly evidenced by the ionization and inelastic impact curves in a device with the grid close to the filament. In another device with a wide grid separation it is demonstrated that the virtual free path of electrons in nitrogen must be several times that predicted by the kinetic theory. It is furthermore shown that the dimensions of the apparatus, particularly the grid distance, determine the appearance of the higher critical points of nitrogen, all the points located by Brandt (resonance point, 8.2; ionization points, 17.7, 25.4 and 30.7) being located although no attempt was made to correct the observed values accurately. Evidence is presented for the suggestion that the 8-volt resonance point and the 17-volt ionization point are characteristic of the atom while the higher points, specifically the 24-volt point, are connected with the ionization of the molecule. Attention is drawn to the important rôle played by the electrodes and gas and metal films in catalyzing dissociations and other reactions in devices of this type. The work is being extended in an attempt to relate the various nitrogen band spectra to the observed potentials of molecular inelasticity.

[The notable paper by Smyth, "The Ionization of Nitrogen by Electron Impact" (*Proc. Royal Soc.*, Ser. A, vol. 104, No. A724, p. 121), which was received after this article was in print, definitely establishes that the normal ionizing action at 17 volts is to form singly charged molecules, N_2^+. However, the potential for ionizing the atom to form N^{++} is deduced by him to be

approximately 18 volts, so that an electron of this energy would ionize an atom as suggested by us above if atoms were provided by filament catalysis. On the other hand, in a molecular atmosphere N_2^+ would be formed. Smyth finds the 24-volt ionization to be represented by $N_2 \rightarrow N^{++} + N$ as suggested by us and locates the third critical point at 28 volts in agreement with our observations.]

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[10] KARRER: *Phys. Rev.*, **13**, 297, 19.
[11] FOOTE and MOHLER: "Origin of Spectra," p. 191.

"Green Struck" spoilage of meats, and especially of poultry, is a matter of economic importance and of scientific interest. PENNINGTON and SHERWOOD (*Poultry Science*, 1922, **1**, 114–124) have studied the causes of the greening of chickens. The typical green coloration is due to the action of bacteria which produce putrefactive changes in the intestine. Hydrogen sulphide is thereby generated, penetrates the thin body wall over the ribs, and acts upon the blood in the capillaries of the skin, converting its hemoglobin into green sulph-hemoglobin. Greening occurs less rapidly if the animal be starved for twenty-four hours prior to slaughter, and does not occur at all if it be cooled to 32° F. immediately after killing and then be kept at that temperature. Precooling to a temperature of 45° F. or less, followed by holding at approximately 55° F. for six or eight days greatly favors greening. The typical green color does not develop at room or higher temperatures; the chicken merely assumes a dull green, bloated appearance. J. S. H.

Ventilation of Cold Storage Rooms.—The "cold storage flavor," which may be noted in cold-stored shell eggs, is not due to any chemical change in the eggs themselves, but is probably absorbed by the eggs from the straw-board "flats" and "fillers" of the package. According to MARY E. PENNINGTON (*Ice and Refrig.*, 1923, **64**, 536–538), aëration of the cold storage room with fresh air deters the absorption of this flavor by the eggs, the temperature of storage being between 29° and 31° F. Moreover, if the air be properly humidified, only the usual shrinkage of the eggs occurs, the total loss in weight per month being approximately ½ per cent. A rapidly moving current of fresh air tends to check the growth of "whiskers" and other molds on the eggs. J. S. H.

THE TIDAL AND CURRENT WORK OF THE COAST AND GEODETIC SURVEY.*

BY

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INTRODUCTION.

It is not the purpose of this paper to furnish an exhaustive treatise on the subject of tides and related phenomena, but rather to give a brief, non-mathematical explanation of the tides and currents from an engineering, or rather, a physical viewpoint for those who have not the time from their own sphere of work to have more than a general interest in the subject. An outline will be made of the activities of the Coast and Geodetic Survey in tidal and current work, with reference to recent investigations in the subject of wind-driven currents; relation and importance of tides and currents to the work of the engineer, mariner and scientist, and a brief description of the instruments and methods employed in the observation and prediction of tides and currents.

The tidal work of the Survey had its origin in the necessity for correcting the soundings taken in hydrographic surveys for the rise and fall of the tides; that is, for reducing to a common level or datum plane soundings made at varying stages of the tide. The further needs of the mariner, engineer and scientist, since the early days of the Survey, have resulted in the development and extension of the work until it covers at the present time the following fields: Determination of datum planes for surveying and other engineering purposes; prediction of tides and currents, and the preparation of annual tide and current tables; study of mean sea level and its relation to crustal movements; study of methods of observing tides and currents and reducing tidal and current observations; development of instruments for observing and predicting tides, and the study of tidal phenomena in general.

Before touching on the modern work in the subject, a brief reference to the development of tidal knowledge may be of interest.

* Presented at a meeting of the Mechanical and Engineering Section of The Franklin Institute, held Thursday, February 8, 1923.

HISTORICAL.

It happens that the maritime people of antiquity, who have left us a history of their times, lived near the Mediterranean Sea, where the tidal range is small and its regular fluctuations frequently modified and at times completely masked by meteorological conditions. Since the tidal phenomena had no economic importance in their everyday life, it received very little attention from both practical and theoretical viewpoints. Though the ancient peoples had scant knowledge of the tides, their regular rise and fall must have been noticed early in ancient times and have been a matter of wonder. This was undoubtedly true in those regions where the range is large and the phenomenon impressive. It is interesting to note, however, that no direct reference to the tides is made in the Bible and even classical literature contains very few such references.

We learn from classical literature that some of the ancient philosophers ascribed all sorts of fanciful motions to the making of the tides; as, for example, that the earth was an animal and the tides caused by its breathing or by the beating of its pulse. Later we find more rational reasons given for the phenomenon—the differences of level of the sea, whirlpools and eddies, the water thrown by the winds against one coast and back toward another, discharge of rivers into the sea, and finally the forces exerted by sun and moon.

It is not known just when the true relation of the moon to tides was first recognized, but it is recorded that as early as the third century before the beginning of the Christian Era, Pytheas of Massilia, who had gone beyond the confines of the Mediterranean and sailed as far north as the British Isles, noted this relationship. Four centuries later Pliny, the Elder, definitely ascribed the moon and sun as makers of the tide.

In the sixteen centuries following there appears to have been no progress toward a solution of the problem of the tides, though the subject received the attention of the leading philosophers. Upon discovery of the law of gravitation by Newton toward the end of the seventeenth century, a rational explanation was furnished of the forces exerted by sun and moon. Newton showed that the tide was a natural consequence of the law of gravitation and having proved this, he did not carry his investigations further,

but left the developing of the different theories to scientists following him.

In the development of the tidal theories naturally the tides of the North Atlantic were the ones with which early investigators were most familiar and the ones on which the earlier theories were based. When observations were extended to other parts of the world by the use of automatic or self-registering tide gauges, which were first introduced in 1831, it was found that the tides in general were not so simple as indicated by these comparatively simple Atlantic tides. The tides of the Pacific were found to be quite different from those of the Atlantic, and those of the Gulf still different from those of the Pacific. This led to a study of the various types and forms of tides.

This study of the types of tides and their geographic distribution has also a directly practical application in the prediction of tides and the preparation of annual tide tables. Since it is physically impossible to predict and publish the times and heights of the tides for all ports in the world, a knowledge of the different types makes it possible to predict the times and heights of each successive high and low water for relatively few harbors as standard ports and to refer other places having similar types to these standard ports. The time and height of the tide in all the harbors of the world may then be obtained from these standard ports, or primary table, by means of time differences and proportionate heights, since, having the same type tide, the character of their variations is also similar. In many cases the subsidiary port does not have to be near the standard port or port of reference; for example, a port in the North Sea may be used as a port of reference for Nelson, a railway terminal on Hudson Bay; and another example, a constant difference exists between the time of low water at Miramichi Bay and high water in the Strait of Georgia, on the opposite side of the continent, the two places having a similar type of tide except that the tide curves are inverted.[1]

TYPES AND FORMS OF TIDES.

Though the tides in different parts of the world assume a number of different types and forms, they may be conveniently classed

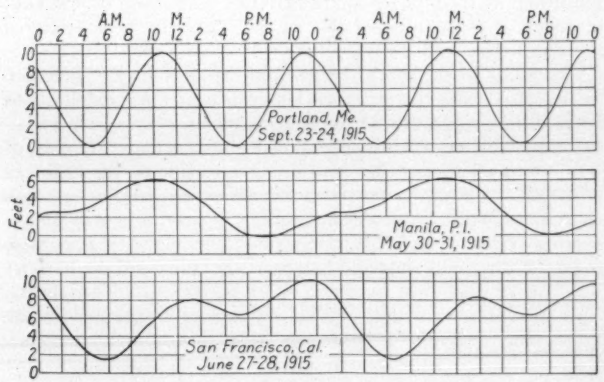
[1] "The Tides and Tidal Streams, with Illustrative Examples from Canadian Waters," W. Bell Dawson, Ottawa, 1920, p. 26.

as three distinct types, with their different forms. The main classification may be made into the *semi-daily*, the *daily* and the *mixed*.

Fig. 1 represents reproductions of automatic tide gauge records at Portland, Maine, Manila and San Francisco, illustrating these simplest types—the semi-daily tide at Portland, the daily at Manila and the mixed type at San Francisco.

The simple form of the *semi-daily* has two high and two low waters each day; also the morning and afternoon tides are very

FIG. 1.



Three types of tide: Semi-daily, daily and mixed.

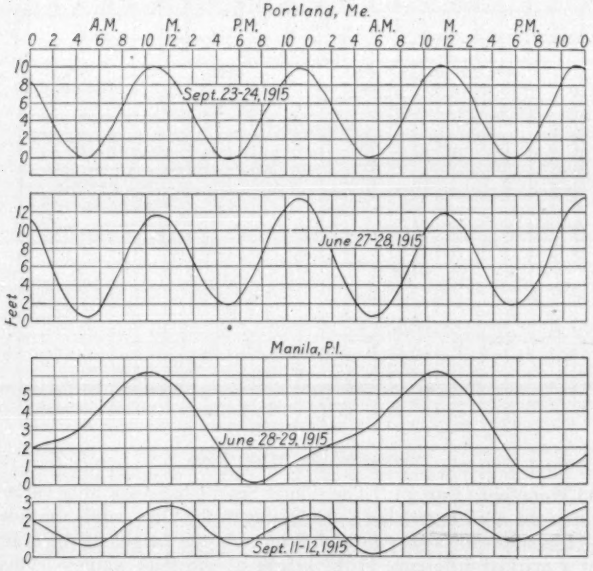
similar. In the simple form of the *daily*, there is only one high water and one low water a day, while the third, ***mixed type***, is caused by a combination of the daily and semi-daily types. It is characteristic of this type that two high and two low waters occur each day, but that the two differ both as to form and height. This type is illustrated by the tide at San Francisco.

Even these simplest types vary with the moon's changing declination. Fig. 2, representing reproductions of the tidal records at Portland, Maine, and Manila, illustrates the variations due to this cause.

The upper tidal graph for Portland is known as an equatorial form, occurring when the moon is nearing the equator. The

lower graph for Portland is the declinational form which occurs when the moon's declination is large. This difference in the heights of the two high waters or two low waters of a day is known as the diurnal inequality in the tides and has been found to be related to the declination of the moon, being least when the moon is on the equator and greatest when the moon is farthest

FIG. 2.



Variation in tidal curves due to changing declination of the moon.

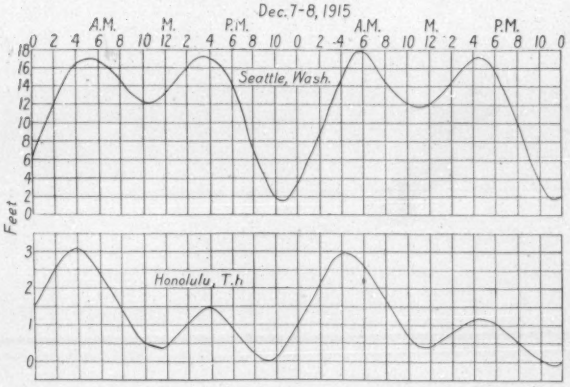
north or south of the equator. At this time of the moon's greatest declination the tides are known as "tropic tides," since at that time the moon is near one of the tropics.

At this port then the semi-daily tide at certain times approaches somewhat the mixed type, though to a minor degree in comparison with a truly mixed type. The records for Manila (lower diagrams, Fig. 2) illustrate, too, a port which ordinarily has a daily

type, having for a few days during a lunar month a semi-daily tide at the time when the moon is nearing the equator, and therefore the semi-daily forces exerting the dominant influence. Likewise, the tide of a port which ordinarily has a mixed type changes for a few days during the month to a semi-daily form when the moon is near the equator.

In addition to these variations we may have two distinct forms of mixed type which are illustrated by the tides at Seattle

FIG. 3.



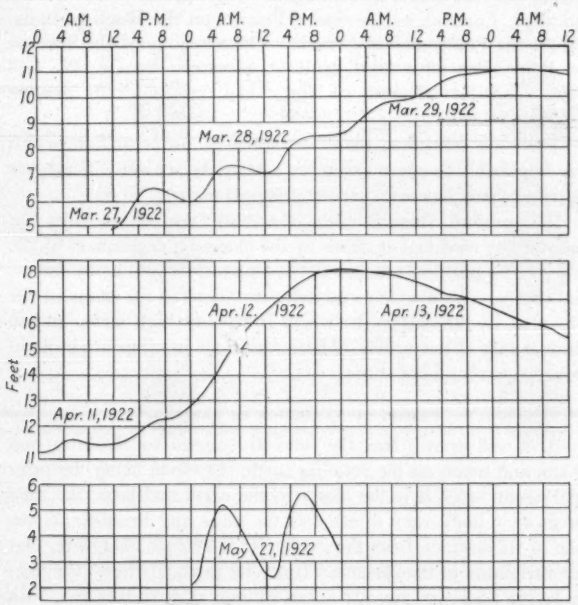
Different forms of mixed type of tide.

and Honolulu (Fig. 3). The tide at Seattle has very little variation in the *high* waters but considerable in the lows, while the tide at Honolulu shows very little difference in the height of the *lows* but a marked difference in the height of the *high* waters. This difference in form is due, briefly, to the different combinations of the daily and semi-daily waves—they may have the same phases and different amplitudes; different phases and the same amplitudes, or both different phases and different amplitudes. It is evident, therefore, that they may combine in various ways giving rise to many other different forms.

Another type is illustrated by the tide in a river which drains a considerable area. The fresh water run-off affects the tidal

wave of the river to some extent, causing the tidal curve to be steep and of a comparatively short period for the flood and more inclined and of a longer period for the ebb. This type is known as the "river type tide" and is illustrated by the tide at Albany (Fig. 4). On the graph for May 27th, the tide was rising four

FIG. 4.



Tidal curves from record at Albany, New York, representing the river type tide and the effects of freshets in upper reaches of a river.

and a half hours and falling eight hours; that is, the curve is steep on the rising tide and more inclined on the ebb.

This type is very pronounced in a number of shallow rivers and estuaries, having considerable range of tide and broad flats, bare or almost bare at low water, the extreme case being represented by the "bore." The tide rises so rapidly that the meeting

of the incoming tide wave with the natural run-off of the river, coupled with the friction of the lower layers of water with the bottom, causes the incoming wave to assume the form of a wall of water, at times several feet high, which rushes up the river or estuary. Probably the most famous bore, as this type has been designated, occurs in the Tsien-Tang Kiang,[2] China, though smaller ones are found in Turnagain Arm, Alaska, on the Severn and Wye, England, on the Seine, France, on the Hugli in India, and on the Petitcodiac in Canada. Observations of the bore on the Petitcodiac have been made at Moncton, by Dr. W. Bell Dawson, Superintendent of the Tidal and Current Survey of Canada.[3]

There are, of course, many variations of forms of tides which it is impossible to cover except as a separate subject. The types described here, however, are the principal ones.

It is evident, then, that the *type* and *form* of the tides are considerably modified at times by the changing declination of the moon or its position relative to the equator, as well as by terrestrial causes. We also have periodic variations in the *range* of the tide; that is, the heights to which it rises at high water and to which it falls at low water. These variations in range are brought about by astronomical causes.

CAUSES OF VARIATION IN RANGE.

It is well known that the tides are caused by the attraction of sun and moon on the rotating earth, the moon being the principal agent, since it is the closer to the earth and since the tidal forces of a body vary directly as the mass and inversely as the cube of its distance from the earth. It is evident, therefore, that any variations in the distances from the earth of these two tide-producing bodies or any variations in their relative positions with reference to the earth will bring about corresponding variations in the tidal forces exerted by them and thus a variation in the range of tide.

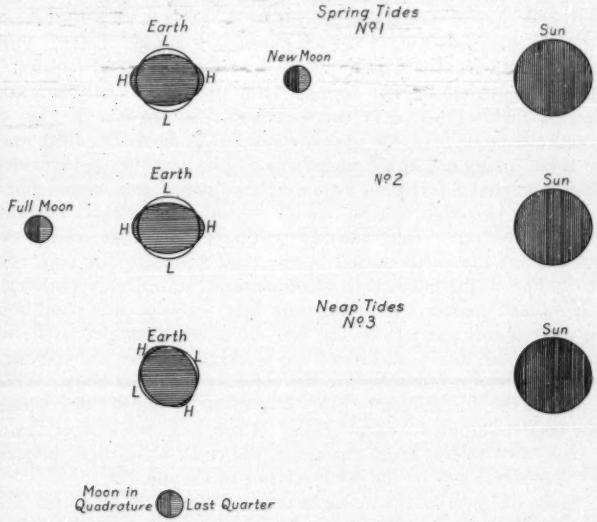
To furnish a non-mathematical illustration of these varying

[2] For description, G. H. Darwin, "Tides and Kindred Phenomena in the Solar System," p. 63.

[3] W. B. Dawson, "Survey of Tides and Currents in Canadian Waters," Ottawa, Canada, p. 23.

astronomical conditions, Fig. 5 assumes the earth to be covered with water at a uniform depth. Now when the moon is over any point its attraction for the water under it is greater than its attraction for the solid earth, and it therefore tends to pull the water away from the earth and thus make high water. Likewise, the moon's attraction for the solid earth is greater than its attrac-

FIG. 5.



A diagrammatic representation of the causes of spring and neap tides and their differences.

tion for the water on the opposite side of the earth from the moon and therefore tends to draw the earth away from it and make high water on the opposite side. Therefore, the moon as it travels around the earth makes in general two high waters each day at a place, one at upper and one at lower transit, with two low waters in between.

While these conditions are not exactly true in nature, the figures will show diagrammatically the causes of the so-called "spring" and "neap" tides and their differences; it is untrue

to nature in that high water does not follow directly under the moon, but has a lag due to viscosity of water, friction and land masses, and that the tidal forces exerted by moon and sun are tangential and not vertical; that is, the direct lifting power of the moon is slight and the water rather is drawn together from the two sides of the earth under the moon.

In No. 1, Fig. 5, the sun and moon are in line relative to the earth, and their tidal forces, due to the action of gravity on the earth and oceans, are therefore acting in concert to bring about the large tides which have been designated "spring" tides. This was probably an unfortunate selection of a name, since "spring" may be confused by the layman with the season of the year, whereas spring tides occur twice each month. In No. 2, Fig. 5, though the moon is on the opposite side of the earth from the sun, the tidal forces are again in unison to produce the spring tides which occurred a fortnight before at the time of new moon, since the moon's two high waters, one on one side of the earth and the other on the other side, combine with the two high waters on each side of the earth caused by the tidal forces of the sun. In No. 3, Fig. 5, the moon is in quadrature or, in ordinary parlance, "In its last quarter," as it happens here. Under this condition the tidal forces exerted by the sun are at right angles to those exerted by the moon, and therefore working against one another, each force tending to minimize the force of the other body. This counter-attraction naturally gives rise to small range tides which have been designated "neap" tides. These neap tides occur again in about two weeks, when the moon has come to its first quarter on the opposite side of the earth relative to the sun.

Since the path of the moon in its orbit describes an ellipse, its distance from the earth varies during the course of the lunar month required for a complete revolution around the earth, and we have variations in range of tide due to this condition. When the moon in its pilgrimage around its parent body is in a position closest to the earth, it is said to be in "perigee" and, being closest to the earth at that time, the tidal forces are therefore stronger than when in the position farthest from the earth. In this position the moon is said to be in "apogee."

Likewise, variations in range of tide are brought about by the varying distances of the earth from the sun as it revolves in its elliptical orbit around the sun, the conditions being somewhat

similar to those for the moon. At the time the earth is closest to the sun, it is said to be in "perihelion"; when it is farthest away, it is said to be in "aphelion."

When it so happens that spring tides occur at the same time that the moon is in perigee, the range of the tide at some places is increased as much as 40 per cent. Likewise, when neap tides occur at the same time that the moon is in apogee, the range is less than the mean by about 40 per cent.

An example from Fort Hamilton, New York Harbor, will serve to illustrate these differences.[4] The spring, neap, apogean, perigean and mean ranges for Fort Hamilton are as follows:

Mean ..... 4.7 feet
Spring ..... 5.6 feet, or 20 per cent. greater than the mean range
Neap ..... 3.8 feet, or 20 per cent. less than the mean range
Perigean .... 5.8 feet, or 23 per cent. greater than the mean range
Apogean .... 3.8 feet, or 20 per cent. less than the mean range

On July 15, 1916, the moon was full and also in perigee. A day later, July 16th, the tide gauge record from Fort Hamilton shows a range of 6.5 feet, or 39 per cent. greater than the average range. This lag of one day in the response of the tide to the tide-producing forces is known as "age of the tide" and is generally ascribed to the effects of friction.

On October 16, 1916, the moon was in its third quarter and also in apogee, the following day the range at Fort Hamilton was 3.2 feet, or 32 per cent. less than the mean range.

This question of types, forms, variations in tidal range and many other problems have required study and solution by tidal mathematicians before tide predictions could be presented to the engineer and the mariner in their present accurate state. In fact, a study of the different types of tides and the behavior of the tides in different parts of the world played a large part in the conception and in the development of the latest tidal theory—the Stationary Wave Theory of Harris, of the Coast and Geodetic Survey.

TIDAL THEORIES.

A detailed consideration of the various tidal theories advanced since the time of Newton would be overstepping the purposes of

[4] H. A. Marmer, "Flood and Ebb in New York Harbor," *Geographical Review*, vol. xiii, July, 1923, p. 420.

this paper, except possibly a brief résumé of the latest.[5] Based on the law of gravitation and Newton's theory, several tidal theories have since been advanced, each looking toward a finally accepted solution of the tidal problem; among them Bernoulli's Equilibrium or Static Theory; Laplace's Dynamic Theory; Airy's Canal Theory; Whewell's Progressive Wave or Southern Ocean Theory and finally the Stationary Wave Theory of Harris. This latest theory is opposed to the older theories. It does away with the idea advanced by previous theories of a single world phenomenon and substitutes regional oscillatory areas as the origin of the dominant tides of the various oceans, these oscillations being set up and maintained by the periodic tidal forces of sun and moon.

We are all familiar with the kind of wave travelling in from the ocean toward the land, and it is evident that a wave in continuous motion does not imply that the water is moving in the same direction; it is only the forward motion of a shape. We have a somewhat similar motion in a rope held in the hand and violently agitated. A wave will travel the length of the rope, the rope itself remaining fixed in so far as progression in the direction of travel of the waves. Such a wave is known as a progressive wave and the older tidal theories depended on the progressive wave to explain the origin of the dominant tides of the various oceans.

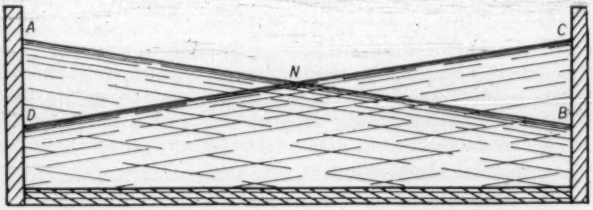
We may also have an altogether different kind of wave travelling through a body of water. Imagine, for a moment, a vessel (Fig. 6) partly filled with water. If we raise and immediately lower one end of the vessel, a wave will be started throughout the vessel and the water put into oscillation, causing a greater depth at one end than at the other, or high water at A (Fig. 6) and low water at B, with a nodal line, or no change of level, at N. As the oscillation continues we have high water at C and low water at D and again a nodal line at N. High water will occur at one end when it is low water at the other, and high or low water will occur simultaneously throughout each half of the tank. This kind of wave is known as the stationary wave.

The period of this wave or oscillation depends upon the length

[5] For general description of the different theories see *Scientific Monthly*, vol. xiv, No. 3, March, 1922, H. A. Marmer, pp. 209–218; for detailed explanation, Harris, "Manual of Tides," Part I, pp. 386–465.

of the tank and the depth of the water, and to cause this oscillation to continue, it is only necessary to continue the disturbing force. If this force be applied at regular intervals which coincide with the period of the vessel, the maximum effect is obtained. Most lakes have a similar oscillation in which the whole body of water swings back and forth with a period of from ten minutes to an hour, and with a range of several inches. These oscillations, known as *Seiches* (Sāsh), are caused by sudden changes in atmospheric pressure or by winds over the lake. Studies of Seiches

FIG. 6.



A graphic illustration of the stationary wave. The basis of the stationary wave theory of the tides.

have been made for a number of lakes and given in detail in various publications.[6]

Such a system of waves, then, in brief forms the basis of the Stationary Wave Theory of Harris; that the dominant tides of the world are the results of stationary waves, except that these oscillations are set up and maintained in the various parts of the oceans by the periodic tidal forces of sun and moon.

The stationary wave theory would thus have the tides in the various oceans distinct problems. They may be due to a progressive wave thrown out by a nearby oscillatory area of the open ocean or, if the size and the depth of the body is such as to maintain an independent stationary wave, its tides may be caused by its own stationary wave; or again, in some bodies of water the tide may be caused partly by a progressive wave and partly by a stationary wave.

[6] G. H. Darwin, "The Tides and Kindred Phenomena in the Solar System," p. 21, and John F. Hayford, "Effects of Winds and Barometric Pressures on the Great Lakes," Carnegie Institution of Washington, 1922.

While from astronomical considerations a mathematical expression for the tide-producing forces may be derived, from which a theoretical tide may be obtained, the actual tides of nature are so modified by land masses that they have little or no resemblance to these theoretical tides. Therefore, for the prediction of the tides at any place, it is necessary first to make actual observations of the tides at that place, extending over a period of a month to a year or more. From these observations constants are obtained which may be introduced into the theoretical expressions for use in predictions of the tides as they occur.

PREDICTION OF TIDES.

For the purposes of predictions the tide is assumed to be composed of a number of elementary or constituent tides, each one due to the motions of the moon and the sun and to their relative positions; and, since the tides are local phenomena, the first step in the making of a tide table for any port is to obtain continuous tidal observations at that port. These observations are then subjected to a mathematical treatment known as the harmonic analysis which resolves the tide into its constituent simple harmonic waves or harmonic constants, the periods of which have astronomical definitions, while the amplitudes and phases are derived from observations. The amplitudes, semi-ranges, and the phases, times of occurrence reckoned from a fixed origin, as obtained from this analysis for each constant, are set on the cranks and dials of a tide-predicting machine. This machine sums the elementary or constituent tides into the tide wave of nature and indicates on its face each successive high and low water which is copied in tabular form, printed, and issued to the mariner as a tide table.

The first tide table of which we have record is one now in the library of the British Museum. It is a manuscript table that appears to have been written in the thirteenth century, and gives the time of the tide at London Bridge relative to the age of the moon and not for calendar days.

In the early days of light draft vessels advance knowledge of the tides was of little importance, but as the draft of vessels approached the depth of water over our bars and in our harbors, such knowledge became of considerable importance to the navigator of a modern vessel on entering and leaving port.

Each of the leading maritime nations issues tide tables, and for the United States this important work is done by the Coast and Geodetic Survey. These tables were first published by the Survey in 1853, and for the first fourteen years they consisted of more or less elaborated means for enabling the mariner to make his own predictions as occasion arose. In 1867 tables were issued for a few ports on each coast of the United States. They have since been considerably increased in scope until at the present time they cover the entire maritime world, and also include the predictions of currents for the United States.

Prior to 1885 the predictions of the tides were computed by means of empirical tables and graphs. Beginning with 1885 the predictions were made by use of an ingenious machine[7] devised by William Ferrel of the Coast and Geodetic Survey. This machine differed somewhat from that of Lord Kelvin, who conceived the idea of such a machine and who devised the first one in 1872. When the predictions were extended by the Survey to cover the world, it was found that the Ferrel machine was not well adapted to the prediction of certain types of tides, and since 1912 the predictions have been made on a new machine, also designed and constructed in the office of the Survey. A view of this machine is shown in Fig. 7. It has been described in a Survey publication, "Description of the United States Coast and Geodetic Survey Tide Predicting Machine No. 2." By use of this machine a tide table for any single port can be made in about ten hours, giving the time and height of every high and low water for every day of the year.

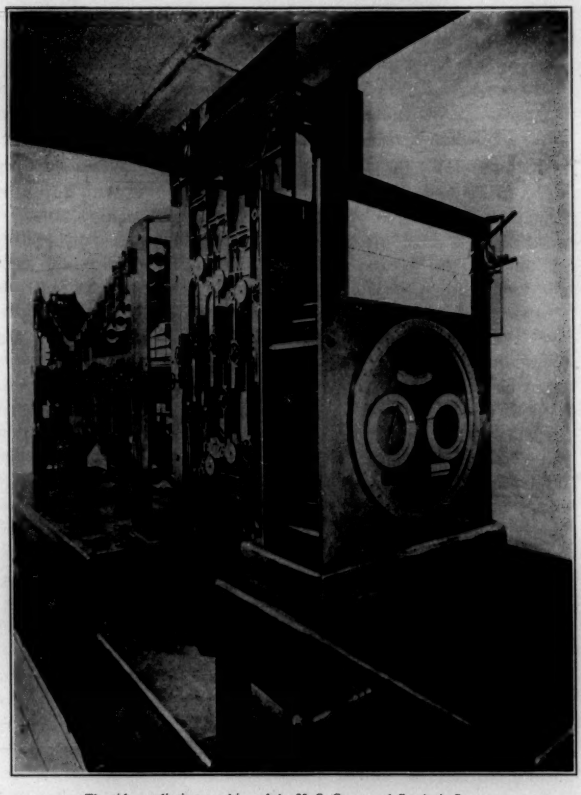
Before beginning the predictions for any port the constants, representing the different components of each constituent tide, are set on the proper cranks and dials which are so arranged that when the machine is put in motion by means of a crank and gears, it will sum up the effects of all these elementary waves into the tide of nature. The machine is also so constructed that this summation is indicated on the dial of the face of the machine as high or low water, and also their times of occurrence. This machine will take account of thirty-seven of these elementary tides.

It is obviously impracticable to predict the tides for all ports. To obtain the state of the tide at places where no full predictions

[7] Appendix No. 10, Coast and Geodetic Survey Report for 1883, p. 253.

are made, it is necessary to refer such places to some port having a similar type tide for which predictions have been made as a

FIG. 7.



The tide predicting machine of the U. S. Coast and Geodetic Survey.

standard port. The Survey predicts for eighty-two standard ports and some 3500 subsidiary ports, covering the entire maritime

world. Therefore, our Navy and Merchant Marine in any port in the world need not depend on foreign sources for their tidal predictions.

The value of a tide table, of course, depends upon the agreement, within practicable limits, of the predictions with the times of the actual occurrence of the tides.

ACCURACY OF TIDE TABLES.

The data used in the prediction of tides, also for mean ranges and lunitidal intervals, for any port, are based on the longest series of observations obtainable for that place. The average of these observations will naturally give the times and heights of the astronomical tide under average or normal meteorological conditions. It is quite evident therefore that exact agreement cannot be expected between predictions and actual times of occurrence, since the times and heights of the tide will be modified by the prevailing meteorological conditions. This is particularly true of upper reaches of rivers, subject to freshet conditions, and also of comparatively shallow bays having small tidal range.

Likewise, in some bodies of water in which the range of tide is small and the depth comparatively shallow, the water will be banked up or blown out by a strong wind, causing considerable differences between predictions and actual tides, and in extreme cases completely masking the regular periodic tide which should occur under normal conditions. As an example, a stiff northwest wind blowing down Chesapeake Bay for a day or so will cause the tides to be later and the heights less than predicted. Then again, a heavy northeast storm piles up the water in the Bay, and we have tides higher than the predicted heights.

The tidal graphs in Fig. 4, which are plotted from actual observations at Albany, New York, will bring out the necessity for long series of observations in a river subject to freshets to obtain final values in tidal data. In the lower graph (May 27th) the periodic tidal fluctuation is only slightly modified by fresh water run-off, low water reading about two and a half feet on the staff and the range being three feet. While on the upper graph (Fig. 4) the tidal fluctuation, though regular on March 27th and 28th, is decreased in range and the whole mean river level raised on the tide staff, until on the 29th the tidal fluctuation has been completely masked by the freshet and the level of the river

has risen to twelve feet on the staff. The middle graph illustrates a similar condition—on April 11th, there was a slight periodic tidal fluctuation, with the river level raised to eleven feet on the staff. This fluctuation is completely masked by 8 P.M., April 12th, with the river level up to eighteen feet on the staff.

It must be stated, however, that the conditions outlined are extreme cases. By far the larger proportion of tidal predictions is made for bodies of water not so greatly influenced by existing meteorological conditions, either because of considerable depth of water or because of large tidal range. To illustrate the closeness of these predictions with the tides as they actually occur at stations not influenced to such a marked degree, the following is quoted from "Tide Tables," by H. A. Marmer (*Geographical Review*, vol. xi, 1921, No. 3, p. 412):

> As a test of the accuracy of tidal predictions, observations and predictions at Portland, Maine, and Seattle, Washington, were compared for the months of May and November, 1919. At Portland the tide is of the semi-daily type and has a rise and fall varying from seven to thirteen feet. At Seattle the tide is of the mixed type with a rise and fall varying from less than two feet to more than sixteen feet.
>
> At Portland for the month of May the greatest difference between the predicted and observed times of tide was four-tenths of an hour, or about twenty-five minutes. For the whole month 59 per cent. of the predicted times differed by not more than one-tenth of an hour from the observed tide, and 94 per cent. by not more than two-tenths of an hour. For November 74 per cent. of the predicted times differed by not more than one-tenth of an hour, and 97 per cent. by not more than two-tenths of an hour—the greatest difference again being four-tenths of an hour.

Further quotations covering the test for Seattle is unnecessary since the percentages are practically the same for that port. It should be borne in mind, however, that no corrections were applied to the predicted time of tide for meteorological conditions; and further, that, near the times of high and low water, the height of the tide is changing slowly, and therefore it is not practical to determine the time of the *observed* high or low water with a precision greater than a tenth of an hour.

It is quite evident therefore that, for purposes of predictions and of a study of the geographic distribution of types of tides in connection with tidal predictions, a continuous record at different places of the rise and fall of the surface of the water of the ocean and tributaries, brought about by the tides, early became of importance to our modern life. These data were needed not only

for commerce in the advance predictions of the future state of the tides in harbors and for the reduction of soundings in hydrographic surveys, but as well were of importance to the theoretical study of the tides in general. These records are also of considerable value to the engineer for defining datum planes; to the geodesist in connection with his level nets and the reduction of his large scheme triangulation system to mean sea level, and to the geologist for testing the stability of coast lines by reference to accurately determined mean sea level.

INSTRUMENTS FOR THE OBSERVATION OF TIDES.

The first instruments or means for the observation of tides naturally were simple, the more complicated and more efficient means evolving in the manner of all instruments, and labor-saving and time-saving devices developed by man. The earliest means were no doubt the marks left by the changing water level, observed by man, on rocky cliffs or ledges; then came the plain graduated tide staff for which an observer was also necessary, and finally the automatic or self-registering gauge, developing, as always developed by man, toward the end of saving to himself time and labor.

The earliest automatic tide gauge (Fig. 8) of which we have record was devised by an English civil engineer, Henry R. Palmer. A paper, descriptive of this gauge, appears in the *Philosophical Transactions of the Royal Society* for the year 1831. This gauge was constructed for obtaining a continuous record of the rise and fall of the tide in the River Thames for getting the effect on the tidal regime of the river by the removal of London Bridge, "Free (as expressed by Mr. Palmer) from the inaccuracies and doubts which the frequent and long-continued observations of individuals through nights and days must be liable."

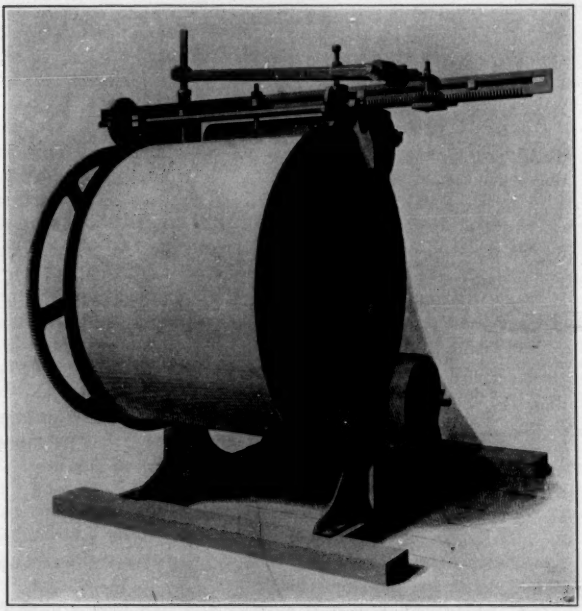
The fundamental principles embodied in this first automatic gauge have not been departed from to a great extent to the present day, with the exception of the special type of pressure gauges, which have been designed for special purposes for which the ordinary type gauge is not suitable. The Favé "Marégraphe Plongeur"[8] is an example of this type.

It is beyond the scope of this paper to illustrate the different individual types of automatic gauges devised in the intervening

[8] *Annals Hydrographique*, vol. 1908–1910, pp. 383–437, and 1921, pp. 193–237.

century. These have been described in various publications.[9] There are many forms of these gauges, but the principle is a simple one. A float is connected by a fine bronze wire or tape with a self-recording pencil or pen which moves at a reduced scale

FIG. 8.



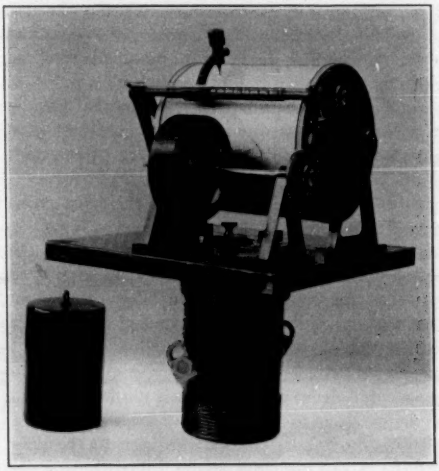
The first automatic tide gauge, designed by a British civil engineer, Henry R. Palmer. (From the *Philosophical Transactions of the Royal Society*, 1831.)

backward and forward across a paper record which is wound on a cylinder, either vertical or horizontal. This paper revolves by means of a clock movement, thus causing the pencil to trace a curve on the paper. This curve or graph is an accurate reproduction of the tide for the locality.

[9] R. A. Harris, "Manual of Tides," Part II, p. 480.

A description of the latest type gauge (Fig. 9), developed by the Coast and Geodetic Survey within the last year for the use of hydrographic and tidal parties in the field, has not yet appeared in print. A considerable number of requests for descriptions and photographs is indicative of a general interest in this portable instrument among engineers, oceanographers and others,

FIG. 9.



Portable field automatic tide gauge, recently developed by the Coast and Geodetic Survey.

and therefore a somewhat detailed description of the gauge appears to be warranted in this paper.

NEW FIELD AUTOMATIC TIDE GAUGE.

The new field type automatic tide gauge was developed by the Survey primarily for providing a portable, easily installed gauge which can be used to advantage by its hydrographic and tidal parties in the field at stations where it is necessary to obtain tidal observations extending over only a few days or weeks for the reduction of soundings taken during the survey, or for compara-

tive purposes. In designing this instrument, the main objects sought were ease of installation and minimum size, commensurate with the desired accuracy.

General Description.—The essential features of the gauge are its small size, its single drum on which the paper record is wound, a single clock movement installed within the drum, a cast base with sleeve to fit on top of a float tube of *stock* 3½-inch iron pipe. This pipe, in addition to serving as a float well, also acts as a support for the instrument, thus obviating the necessity of providing elaborate platform and cumbersome float well. This feature alone renders the gauge more adaptable for use by field parties, particularly in remote localities where wharves and docks are not available. Another departure from the usual design of automatic gauge is the use of a spring counterpoise instead of counterpoise weights for taking up the slack of the float wire on a rising tide.

The gauge is ten inches square on the base and, with its weather-proof metal cover in place, is ten inches high. The gauge base locks by means of two hook-screws into the top section of the float well; the weather-proof cover is then locked in place by two padlocks, so that the mechanism is completely covered and cannot be tampered with when the gauge is installed in exposed places.

Drum for Paper.—The drum on which the paper record is wound is a single cylinder 7 inches long, and 19.2 inches in circumference. This drum is geared to a clock movement carried within the drum, so as to rotate once in forty-eight hours, giving a time coördinate of four-tenths of an inch to the hour. Upon unclamping the milled head nut at the top of the standard on the right side of the instrument (Fig. 9), the drum may be freely turned and the pencil set on cross-section paper to the nearest ten minutes of the time coördinate of this cross-section paper. A tangent screw (added after photograph was taken) on the pencil arm permits of setting the pencil to the nearest minute.

Paper Record.—The tidal graph is made on sheets of cross-section paper 7″ × 19.7″, allowing in length for a half-inch overlap. The record paper is wrapped around the cylinder and held in place by two ordinary rubber bands, one at each end of the drum. The use of five different scales of cross-section paper permits the reproduction of tidal graphs to five reduced scales, allowing therefore for the accommodation to suitable scales of

ranges of tide from zero to twenty-four feet. The time coördinates on these sheets of paper are lines ruled parallel to the short edge of the paper, moderately heavy lines four-tenths of an inch apart for the hours, these spaces equally subdivided into six spaces by lighter lines for ten-minute intervals. The hour lines are numbered through two twenty-four-hour periods, thus providing for the forty-eight hours of a complete rotation of the drum. For the height coördinates the sheets are ruled with lines parallel to the long edge of the paper, moderately heavy lines for the foot marks and lighter lines for subdivisions of two-tenths of a foot. The smallest scale, however, for a tide of sixteen to twenty-four feet, is subdivided into one-half foot only, instead of two-tenths of a foot subdivision of the larger scales.

Pencil Screw.—The pencil screw of phosphor bronze has a pitch of four-tenths of an inch and is connected to the axle of the float pulley by means of two gear wheels and an idler gear wheel. Several sets of these gears are furnished so that the scale of reproduction of the tidal curve may be determined by the relation of the diameters of the two gear wheels employed. For adjusting the pencil when installing the gauge to the height of the tide as read on a fixed graduated tide staff, the milled nut holding the upper gear wheel to the pencil screw is unclamped and the pencil screw then turned freely without connection to the float pulley until the pencil point indicates on the cross-section paper record the height of the tide at that particular time on the graduated fixed staff. This milled nut is then clamped and the pencilled curve will thereafter indicate on the record the reading at any instant of the water level on the fixed tide staff as the tide rises and falls.

Counterpoise Spring.—Instead of employing the usual counterpoise weight for taking up the slack of the float wire on a rising tide, a coiled flat spring 18 feet long, 0.25 inch wide and 0.010 inch in thickness is used. This spring is coiled within the case of the float wire pulley, one end fastened to the inside of the outer periphery of the metal case, the other end fastened to a separate extension of the pulley axle. This subsidiary axle extending to the left of the float pulley (Fig. 9) is controlled by a ratchet and pawl, so that any desired tension may be put on the spring.

In actual practice the more accurate results may be obtained by using the middle of the spring. This is accomplished, when

installing the gauge, by fully winding the spring which requires thirty-eight turns; it is then unwound nineteen turns, provided the water level at the time is at approximate mean sea level. If the height of the water at the time is not at mean sea level, the spring is unwound or wound the same number of turns that the water is above or below mean sea level in feet.

Float.—The float, a hollow brass cylinder, 3¼ inches in diameter and 15 inches long, connects the water level to the mechanism by means of a phosphor bronze wire 0.012 inch in diameter. This float is weighted with shot to float in kerosene oil with its upper end one-half inch above the surface, the oil preventing freezing of the water in the float well in winter. The weight of the float and shot is sufficient to wind the counterpoise spring on a falling tide and at the same time to actuate the recording pencil with a uniform motion.

Float Pipe.—The float pipe consists of a section, or sections, of ordinary stock 3½-inch iron pipe. A special bronze casting is furnished with the gauge, having an inverted cone cast inside. A quarter-inch hole drilled at the bottom of this inverted cone allows ingress and egress of the tide to the float well. The inclined surface of this cone permits of easily cleaning the pipe of any obstructions which might affect the entrance of water to the pipe.

When it is necessary to install the gauge in a place at which no wharf or platform is available and to have the float pipe carry the weight of the gauge as a standard, another length of the pipe is screwed into this cone casting on its bottom end and perforated with a number of large holes to allow free access of the water to the opening in the casting.

Clock.—The clock is an ordinary eight-day movement, mounted within the drum which carries the paper record. The gauge when properly adjusted, which does not require a high degree of skill in the use of instruments, will operate for eight days without attention in the meantime. The drum on which the paper record is wound turns once in two days; and, since the lunar and solar days are of different lengths, the tidal curve advances sufficiently from one turn of the drum to the next to obviate any interference of the curve for any day with that of the second day following.

Float Pulley.—The phosphor bronze wire, connecting the float with the mechanism, is wound on a threaded float pulley exactly

twelve inches in circumference. This pulley is rigidly fixed to that part of the axle which extends to the right (Fig. 9), terminating with a gear wheel. The relation of the circumference of this pulley, the relative sizes of the uppermost and lowest gear wheels and the pitch of the pencil screw determines the scale of reduction of the tidal curve.

Shelter.—A weather-tight galvanized metal cover, with means for locking to the base of the instrument to prevent unauthorized tampering with it, protects the instrument from rain and spray. This cover fits closely around the base of the instrument and no other shelter is necessary.

(To be concluded.)

Detection of Methanol in Presence of Ethanol.—To lessen the tendency to use of methyl alcohol—commonly called "wood spirit"—as a beverage, it has been generally agreed among public analysts and sanitarians to apply the term "methanol" to the substance. Its detection has long been a matter of importance on account of its use as a substitute or adulterant of common alcohol. It has very poisonous action. Of late the detection of it has become of very great importance on account of the restriction placed on the sale of common alcohol (ethanol) for beverage purposes. One source of serious injury is the partial purification of ordinary denatured alcohol which contains crude methanol. Many tests for methanol have been devised. LaWall (*Trans. Wagner Free Inst. Sci.*, 1923, 10; also *Amer. Jour. Pharm.*, 1923, **95**, 812) has investigated the more important tests and finds that that prescribed in U.S.P. (ix) is, with slight modifications, delicate and trustworthy. It is as follows:

Dilute the sample until it contains not more than 5 per cent. by volume of ethanol. To 5 c.c. of this add five drops of syrupy phosphoric acid and 2 c.c. of a 3 per cent. solution of potassium permanganate. The test is most convenient made in a test-tube holding 20 c.c. Allow the mixture to stand for ten minutes, then add 1 c.c. of a 10 per cent. solution of crystallized oxalic acid and allow to stand until the solution becomes a transparent brown. Now add 5 c.c. of a cold dilute sulphuric acid (one volume of acid to three volumes of water), then 5 c.c. of a fuchsin-sulphurous acid solution and allow to stand for ten minutes. The liquid should show no trace of blue or violet.

The fuchsin-sulphurous acid is prepared by dissolving 0.5 gram of basic fuchsin and 9 grams of sodium bisulphite in 450 c.c. of water, adding 10 c.c. of strong hydrochloric acid and making up to 500 c.c. This solution should be kept in the dark. H. L.

The Volume Changes of Five Gases under High Pressures. P. W. BRIDGMAN. (*Proc. Nat. Acad. Sci.*, Nov., 1923.)—Thirty years ago Amagat examined the compressibilities of hydrogen and nitrogen under pressures extending to 3000 kg. per square centimetre. In this paper the range for nitrogen, helium and argon is brought up to five times the former maximum pressure, while for hydrogen and ammonia it remains somewhat less.

Under these enormous pressures Boyle's law is far from being followed. According to it, increasing the pressure from 3000 to 15,000 kg./cm.^{2} should reduce the volume of nitrogen to one-fifth of what it was at the lower pressure. In fact, however, this change of pressure merely causes the volume of the gas at 68° C. to change from 36.13 to 25.43.

"The densities under 15,000 kg. are as follows: Hydrogen, 0.1301 (extrapolated from 13,000); helium, 0.340; and nitrogen, 1.102. These densities are greater than the densities of the liquid or solid phases of these substances under reduced temperatures at atmospheric pressure. Thus the density of liquid hydrogen is ordinarily given as 0.070, and that of the solid as 0.076; the density of liquid helium is 0.1456; and that of liquid nitrogen is in the neighborhood of 0.85. These figures enable lower limits to be placed on the compressibility of the liquid and solid phases, quantities for which previously we have had no idea of the order of magnitude. It appears that the compressibilities of solid and liquid hydrogen and of liquid helium are by far the greatest ever found for a solid or liquid, and it is probable that these are the most compressible liquids and solids." No equation of state seems to fit the experimental results, though an equation recently proposed by Becker predicts the changes in nitrogen quite well. G. F. S.

A Determination of e/m from Measurements of the Zeeman Effect. H. D. BABCOCK. (*Astrophys. J.*, Oct., 1923.)—Webster and Page have given 1.7686×10^7 as the most accurate value of the ratio of the electrical charge of an electron to its mass. Birge gives it as 1.758×10^7 and suggests that a new determination be made from the Zeeman effect. When a line is converted into three lines by the application of a magnetic field, the ratio e/m is a function of the velocity of light in the medium where the wave-lengths are measured, the strength of the magnetic field, the wave-length of the original line and finally of the difference in wave-length between the original line and one of the outer lines of the triplet. From this e/m can be calculated.

A field strength of about 30,000 gausses was used. Chromium, zinc, barium and titanium lines were measured in the magnetic field. The weighted mean of the determination from 49 plates is $e/m = 1.761 \times 10^7$, with a probable error of one part in 1800. G. F. S.

PLASTICITY AND ELASTICITY.*

BY

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Elasticity.—The elasticians conceived of matter as more or less perfectly elastic but only infrequently was the flow of matter referred to as the *cause* of this imperfection. So long as plastic flow is conceived of as a lack of perfection in elasticity, we must not expect a rapid expansion in our knowledge of the flow of solids. Indeed, we may expect to gain a clearer idea of the nature of elasticity as we understand more in regard to the nature of plastic flow.

There are two methods for distinguishing between a solid and a fluid. The one is based on elasticity, the other on properties of flow. These methods are mutually contradictory unless it can be shown that plasticity and elasticity are closely related.

In his classical article on "Elasticity" [1] in the ninth edition of the "Encyclopedia Brittanica," Lord Kelvin states that "if a body possesses any degree of elasticity of shape, it is called a solid; if it possesses no degree of elasticity of shape it is called a fluid."

This definition of a solid is at least superficially very different from that of Maxwell expressed in his "Theory of Heat." [2]

"If the form of the body is found to be permanently altered when the stress exceeds a *certain* value, the body is said to be soft or plastic. If the stress, when it is maintained constant, causes a strain or displacement in the body which increases continually with the time, the substance is said to be viscous.

"When this continuous alteration of form is only produced by stresses exceeding a *certain* value, the substance is called a solid, however soft it may be, when the smallest stress, if continued long enough, will cause a constantly increasing change of form, the body must be regarded as a viscous liquid, however hard it may be."

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* Communicated by the Author.

[1] "Mathematical and Physical Papers," vol. 3, p. 3.

[2] P. 302.

Whether these two definitions are equivalent hangs upon the definition of elasticity. According to Lord Kelvin[3] "elasticity of matter is that property in virtue of which a body requires force to change its bulk or shape and requires a *continued* application of the force to maintain the change, and springs back when the force is removed, and, if left at rest without the force, does not *remain* at rest except in its previous bulk and shape. The elasticity is said to be perfect when the body always requires the same force to *keep* it at rest, in the same bulk and shape and at the same temperature, through whatever variation of bulk, shape, and temperature it has been brought. A body is said to possess some degree of elasticity if it requires any force to keep it in any particular bulk or shape." (The italics are mine.)

There is then elasticity of bulk and elasticity of shape. Fluids have perfect elasticity of bulk but they can have no elasticity of shape. Elasticity of shape in fluids, as defined by Lord Kelvin, is ruled out by the italicized words in the definition. Solids have imperfect elasticity of bulk and also varying degrees of elasticity of shape. This seems to harmonize the two different definitions of a solid, by assuming that fluids as defined by Lord Kelvin do not possess any elasticity of shape. But a fundamental difficulty remains.

Glass is generally regarded as an undercooled liquid[4] and it, therefore, should show no elasticity of shape; yet it does require force to change its shape, it requires a continued application of force to maintain the change if not too prolonged, the length of time depending largely upon the temperature; and, it springs back immediately, even though not completely when the force is removed. In most discussions of elasticity, glass is cited as an example of a highly elastic substance, as judged by its behavior. But if glass is really a fluid and we accept Lord Kelvin's definitions, it can show no elasticity of shape. But why limit elasticity of shape to solids? Are not elastic deformations entirely distinct from and independent of plastic or viscous deformations? Elastic deformations may be nearly instantaneous in character assuming the mass to be small in comparison with the deforming force, but

[3] "Mathematical and Physical Papers," vol. 3, p. 3.

[4] It has never yet been proven whether glass is a viscous liquid or a plastic solid. *Cf.* Travers, Dept. Sci. and Indust. Research, "The Physics and Chemistry of Colloids," 62 (1921).

viscous and plastic deformations require time for their consummation. Since glass, pitch and other highly viscous liquids show resilience, must we not either apply the term elasticity to them, preferably *instantaneous elasticity*, or else invent a new term to be its equivalent for fluids? And assuming this to be true, is it not possible that many if not all fluids will be found to show this instantaneous elasticity, if studied with sufficiently delicate instruments?

Following out this distinction made so clearly by Maxwell, we arrive at a new definition of elasticity which avoids the diffi-

FIG. 1.

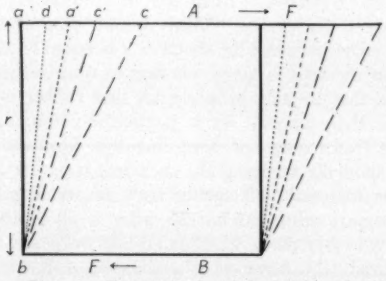

Diagram to illustrate elastic and plastic deformation.

culty encountered above. Elasticity of shape is that property of matter in virtue of which it is immediately deformed by a shearing stress, but reacts against that stress and at once returns to its original shape as soon as the deforming force is removed, provided that the deforming force is removed before the stored up energy is dissipated in either viscous or plastic flow. With many fluids it is difficult to remove the force before the energy has all been dissipated as heat in viscous flow. With viscous liquids and solids above elastic limit a portion of the energy is thus dissipated and they are, therefore, described as having imperfect elasticity.

Varieties of Flow.—This brings us to the point of view that elasticity of shape is not confined to solids, but that it is a universal property of matter. If asked whether rubber, for example, exhibits elasticity or not, we do not need to withhold judgment until it is determined whether rubber is to be regarded

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as a very viscous liquid or a plastic solid. To make this point of view clearer, let us imagine a substance subjected to shearing stress, a section through a portion confined between two imaginary planes A and B being represented in Fig. 1. Let the shearing stress per unit area of either plane be represented by F dynes. Due to the elasticity of the material, a point a will *immediately* move over to a point a' in reference to a point b in the plane B, which may, for the sake of simplicity, be considered at rest. According to Hooke's law, the distance $aa' = s$ will be exactly proportional to the force or

$$s = F\varepsilon r$$

where ε is the *coefficient of elasticity*[5] of the material and r is the distance between the planes. With a unit cube and a shearing force of one dyne per cm.^{2} the distance s is equal to the elasticity. In rubber this distance is large whereas in quartz this distance is very small, so that we may properly say that rubber is much more highly elastic than quartz. It is particularly important to note that the time factor does not come into this formula.

If after suddenly applying the shearing stress, it is as quickly removed, the material will spring back to its original position and in this respect solids can hardly differ from fluids, because in order for flow to take place, whether viscous or plastic in character, time is required. If, however, the shearing force is maintained at a constant value, several things may happen.

1. The deformation may continue at a velocity v which is directly proportional to the shearing stress or

$$v = F\varphi r$$

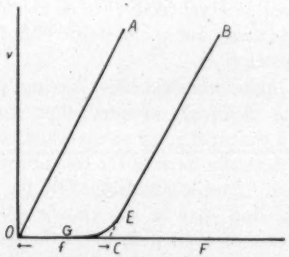
In this case the substance is a *viscous liquid* and φ is its fluidity. The time factor enters in in the measurement of the velocity; energy is continually being absorbed as long as the shearing force acts and quite in contrast to the constant energy absorption in elastic deformation. If energy is not continually supplied, the shearing stress must sooner or later disappear drawing upon the supply of energy stored up in the elastic deformation, so that

[5] To the novitiate the terms used in connection with elasticity are confusing. We here follow the usage of Anthony, Brackett, and Magie, in their "Textbook of Physics," 8th ed., p. 116. They say, "The ratio of the stress applied to the strain . . . is called the *modulus of elasticity* of the body, or simply its elasticity; its reciprocal is the *coefficient of elasticity*." *Cf.* Müller Pouillets' "Lehrbuch der Physik," p. 328, 8th ed.

all of the energy supplied will eventually disappear in overcoming the viscous resistance. Rubber yields continually under comparatively small shearing stresses, so according to the somewhat confusing terminology of the elasticians we must say that rubber is less "perfectly elastic" than quartz even though, as we have just seen, rubber has a much higher elastic coefficient.

2. There may be no further deformation as the stress continues to be applied up to the point of rupture, in which case the substance would exhibit "perfect elasticity." Such a substance is indubitably a *solid* and is perhaps best represented by quartz.

FIG. 2.



Deformation stress diagram illustrating viscous and plastic and pseudo-plastic flow.

The elastic coefficients of such substances might vary within the widest limits.

3. We have the possibility that no further deformation will take place so long as the shearing stress does not exceed a certain value known as the *yield value f*, and that after this force is exceeded, the deformation will take place, perhaps according to the formula

$$v = (F - f)\mu r$$

where μ is the mobility of the material. Such a substance would follow Hooke's law up to the yield value and then suddenly break down and undergo true plastic flow. Alloy steel may serve as an example of this type.

4. Since solids never show "perfect elasticity," types 2 and 3 are only approximately realized. Hooke's law is never exactly obeyed even at very small stresses, so that there is a certain amount

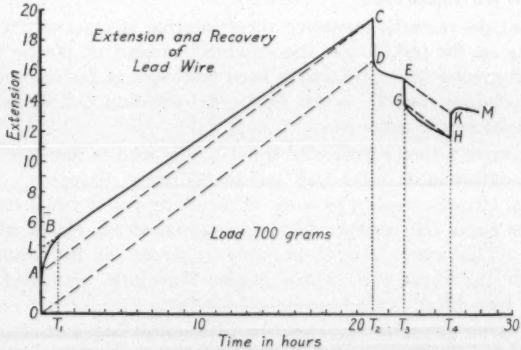
of yielding long before the elastic limit where Hooke's law definitely breaks down.

In Fig. 2, we have plotted velocities against shearing stresses. A truly viscous substance gives a curve OA which is linear until the flow becomes turbulent and which passes through the origin, type 1. A truly plastic solid behaves like a perfectly elastic solid up to a certain shearing stress f, following along the axis OC, type 2. We then get the curve BC, on further increasing the shearing stress. With most solids the lower part of the curve BC seems never to be realized, for reasons which we will discuss later; but the curve bends off toward the origin giving the portion EG. Over the small interval from O to G, the substance follows Hooke's law quite exactly but at the elastic limit G the deviations begin to be quite perceptible.

Were matter quite homogeneous, having similar particles equally spaced and identically oriented, flow would presumably not take place until the yield point was reached and then it would start abruptly. Practically some of the constituents have a higher fluidity than others. Due to accident solely the particles whose friction resists the flow may be less closely grouped at certain points; or in the case of crystalline solids the space lattices may be so oriented at certain regions that the slip planes will lie very nearly in the direction of the shearing stresses. Be the cause what it may, there results a local yielding considerably before the true yield point is reached. As portions of a given layer yield, added stress is placed upon the remaining portions which are then further deformed both elastically and by further breaking down where weakest. This process being continued results in a slow flow taking place which we may call pseudo-plastic flow. This type of flow plays an important rôle in metallurgy. If in Fig. 1, the shearing stress F is supposed to act for a definite time t, the pseudo-plastic flow causes the point a to move beyond a' to c. If the shearing stress is now removed, the material will spring back, not to a but to a point c', so that $aa' = cc'$. But this restoration is not enough for parts of certain layers have been subjected to additional elastic deformation and they too tend to come back into their initial condition; but since portions of the material have yielded this cannot take place instantaneously. The result is that

stresses appear *within* the material which tend to make those portions which have yielded yield again in the opposite direction. In a viscous liquid we should expect the yielding at any moment to be proportional to the internal stresses, but since the flow absorbs energy, the rate of flow must rapidly decrease. This is the so-called elastic after-effect of Weber which has been so thoroughly investigated in wires under tension or torsion. We would expect it to be well exemplified only in materials which

FIG. 3.



Strain-time diagram after Trouton and Rankine, showing elastic deformation *OA*, pseudo-plastic deformation *AB*, plastic deformation *BC*, elastic recovery *CD*, pseudo-plastic recovery *DE*, etc.

have a high instantaneous elastic coefficient. In the figure the slow recovery causes the point c' to move to d.

The Stress-time Curves.—Experiments by Trouton and Rankine[6] in the stretching and torsion of lead wires beyond their elastic limit are instructive in this connection. In Fig. 3, we give a stress-time curve from their work. The curve starts at a finite value of the strain OA, corresponding to the elastic deformation when the wire is loaded instantaneously. The stress being beyond the elastic limit, the strain increases with the time at first rapidly and then more and more slowly along AB until the strain finally increases at a constant rate BC. The slope of this linear part of the curve is of course dependent upon the stress employed, but it is

[6] *Phil. Mag.* [6], **8**, 538 (1904).

a measure of the mobility of the material. This phenomenon is exhibited in as widely different materials as metals, glass and pitch.

As to the cause of the phenomenon, it appears that at the beginning the weak portions have not as yet yielded, hence those internal stresses have not yet developed which are continually trying to obliterate the strain. Therefore, as these internal stresses develop, they reduce the rate of deformation, but there is finally reached a time T_1 when these internal stresses are disappearing as fast as they are being formed, so that the curve BC is linear, for this particular load.

Had the material possessed these internal stresses at the beginning of the test, to get the observed amount of plastic flow a much greater load would have been necessary at the beginning, corresponding roughly to the elastic deformation OL found by extrapolating the curve BC.

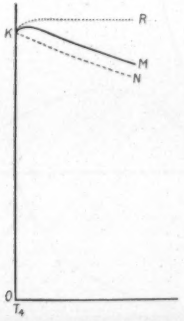
If, after a time represented by OT_2, the load is removed, the elastic deformation $CD = OA$ will immediately disappear. The internal stresses remain, to work in removing the residual strain, and the curve DE results which corresponds to the elastic after-effect. This curve DE is properly regarded as the counterpart of the curve AB, which might, therefore, be called the elastic fore-effect.

If, after the time T_3, when the after-effect has partially disappeared, a small reverse load is put on, the strain will immediately fall elastically to G and then through the development of a new set of internal strains to H. On removing this load the elastic deformation HK disappears at once. The after-effect curve KM is less pronounced than the curve DE corresponding to the smaller load but the recovery is nevertheless considerable during the first few moments after the load is removed.

If certain points in a material are points of weakness for a given direction of flow, it does not follow that the same places will be points of especial weakness when the direction of the shearing stresses is changed. So, since the effects of the internal stresses due to the first loading would have continued on indefinitely had there been no second loading, we may imagine that they will continue when there is a further load applied. The strain which at the time T_4 is represented by T_4K, represented on an enlarged

scale in Fig. 4, does not decay along the curve KR as it would do if recovering from the second loading alone. We have to take account of the recovery from the first loading represented by the curve KN, so the actual curve of recovery observed is KM which shows the strain apparently first *increasing and then decreasing*. By subjecting a sample to a variety of external stresses it is possible to obtain a recovery that is most erratic, due to the superposition of after-effects. Similar considerations apply when dealing with

FIG. 4.



Strain-time diagram illustrating superposition of elastic after-effects, KN—recovery from initial deformation, KR—recovery from second deformation in opposite direction, KM—combined recovery showing strain first increasing and then decreasing.

the fore-effect and emphasize the necessity for the complete removal of the internal stresses if the pseudo-plastic flow is to be studied. On the contrary, if the plasticity of a material is to be measured, it would appear to be necessary to develop the internal stresses in a given direction to their maximum.

The Stress-strain Diagram.—From the above discussion it appears clear that stress-strain diagrams may be quite misleading beyond the elastic limit if, as is usually the case, the time factor is lost sight of.

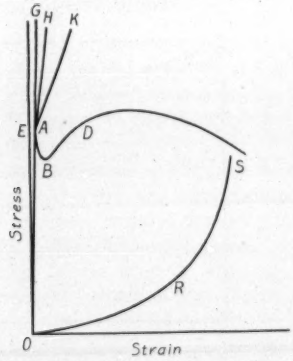
If the load could be applied instantaneously it seems likely that Hooke's law

$$\text{stress} = c \times \text{strain}$$

where c is constant and proportional to the rigidity, would apply

considerably beyond the elastic limit E in Fig. 5, and even beyond the yield point as AG. When the stresses are applied for a given length of time the curve obtained would in general not be the same but OAH. The exact position of this curve is dependent not alone on the time during which the stresses have acted but also upon the structure of the material and to some extent upon the method of measurement. For this reason the stress-strain dia-

FIG. 5.



The effect of plastic flow on stress-strain diagrams.

grams of such materials as iron and rubber are very different as well as characteristic and they need extended explanation. In a test made by Dalby,[7] a specimen of mild steel, 10 inches long and ⅝ inch in diameter, 5 inches between the gauge marks was stretched to its yield point in 0.5 second. The specimen then yielded and the load diminished for 0.25 second as shown by the curve AB in Fig. 5, but there followed the well-known "hardening" brought about by the flow, so that in order to further increase the strain it was necessary to increase the stress for a period of over 0.5 second BD up to a value considerably in excess of the yield-point load. This hardening or "firming up" is especially characteristic of rubber whose stress-strain curve is indicated in

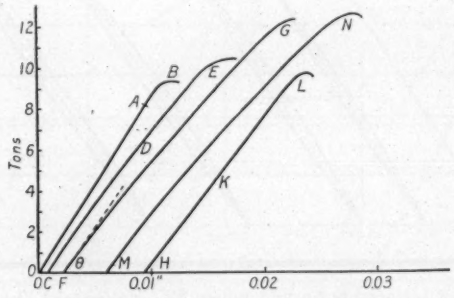
[7] *Phil. Trans.*, **221A**, 117 (1921).

the figure by *ORS*. Rubber does not show an elastic limit short of the breaking-point.

Dalby has given quite an insight into the nature of plastic flow by an ingenious device whereby the load may be very quickly taken off and reapplied and the behavior of the specimen observed continuously.

For example a 3 per cent. nickel steel gave a stress-strain curve *OAB* in Fig. 6, the metal following Hooke's law up to the elastic limit of eight tons per square inch. After stretching, the load was taken off and the piece came back to an extension indicated

FIG. 6.



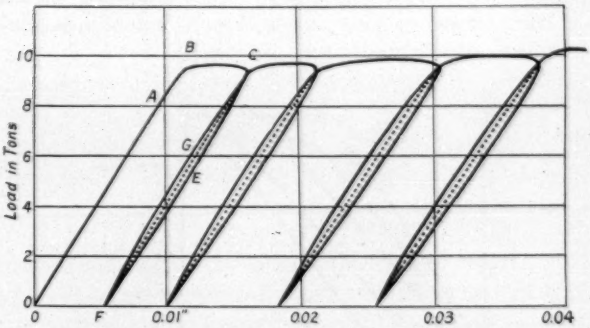
Stress-strain diagram of steel, after Dalby.

by the point *C*. On now loading the specimen again *CDE* it does not follow Hooke's law and no definite elastic limit can be placed. The yield point is quite definitely raised. A repetition of the process of unloading and loading *FG* still further raises the yield point but it does not restore the law of proportionality and it is not restored by allowing the specimen to stand twenty-four hours or by boiling it for an hour *MN*. It shows complete recovery *HKL* by being heated for a half hour in a muffle furnace at 550° C., except that the rigidity, measured by the slope, is smaller.

The most puzzling fact to explain is the failure of the specimen which has undergone pseudo-plastic flow to obey Hooke's law, the rate of elongation constantly increasing as the stress is increased. We get a clearer idea of the phenomenon when the

stress-strain record is kept continuously during a number of repetitions of the stresses, as shown in Fig. 7, for nickel steel. The unstrained metal follows Hooke's law to the elastic limit *A*, it elongates by elastic deformation and pseudo-plastic flow to the yield point *B*. The load is removed at *C* and the specimen recovers along the curve *CEF*, the elongation *OF* remaining after the load is entirely removed. When the load is reapplied, the curve

FIG. 7.



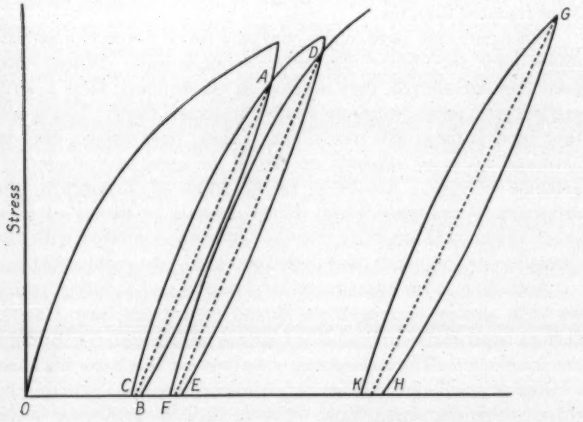
Stress-strain diagram of nickel steel under repeated stresses, after Dalby.

CEF is not retraced but a new curve *FGC* is formed, thus giving a definite hysteresis loop. As the stresses are repeated these loops become larger, the yield point is raised, the rate of increase in the elongation becomes greater, and the rigidity smaller.

The explanation of the phenomenon is probably as follows: The first deformation *OA* is almost entirely elastic, but with further stretching internal stresses are developed. On unloading the material recovers not only the elastic deformation but also an additional amount due to the elastic after-effect, hence the shape of the curve *CEF*. After partial recovery at *F*, the material is under no external stress but it is still under the influence of internal stresses which deform it elastically in a direction opposite to the previous external stresses. Were the load not immediately reapplied the specimen would shorten due to the action of these stresses. The result is that when the load is again applied, the test

piece is deformed elastically more readily than before and owing to the gradual decay of these internal stresses the rate of increase in the elongation increases. It is interesting to observe that this increase in the rate of elongation takes place in spite of a gradual elevation of the yield point. The internal stresses produced by the first loadings do not entirely die away before the successive new loadings, so the increase in the size of the loops is to be explained as merely a case of the superposition of elastic after-

FIG. 8.



Stress-strain diagram of zinc under repeated stresses, after Dalby.

effects. The area of the loops is a measure of the work done by the internal forces, in producing the flow.

This explanation applies satisfactorily to other metals. For example, zinc undergoes plastic flow very easily, it has no well-defined elastic limit but appears to begin to flow as soon as the first load is applied; and the hysteresis curves are extraordinary, as shown in Fig. 8. The curve OA represents the first extension, and AB the recovery under diminishing load. At the point B the specimen was allowed to rest 1.5 minutes without load, so the portion BC represents the recovery under the influence of the

internal stresses. This study makes it evident why zinc cannot be employed to sustain continuous stresses of any magnitude, such as in rivets. The increasing size of the hysteresis loops indicates that the rate of extension of the specimen will increase rapidly under repeated loadings and thus the metal will exhibit a lack of toughness. Copper, on the other hand, exhibits toughness, for although the pure metal does not give a definite elastic limit, the hysteresis loops are small and they do not increase appreciably in size under successive loadings. Since the internal stresses quickly sink to a negligible value, copper does not yield appreciably faster after repeated loadings.

Since pure zinc, pure copper, and pure tin do not have a definite elastic limit, they behave like very viscous liquids. When, however, they are alloyed, they develop an elastic limit, have a well-marked yield point, and show smaller hysteresis loops. In a word, they become more like true solids. Thus, pure copper may be hardened by small amounts of arsenic or even by considerable amounts of *zinc*. According to the ideas of Rosenhain, the distortion of the space lattice of the crystals by means of even small amounts of impurity may considerably interfere with the formation of slip bands, and therefore elevate the yield value.

According to the experiments of Trouton and Rankine, which we have already described, we should expect the loop area in Dalby's experiments to gradually increase with successive loadings to a maximum. The experiments clearly show this to be the case.

Rigidity.—Simple rigidity refers to resistance to distortion of shape within the elastic limit. The coefficient of rigidity is the reciprocal of the coefficient of elasticity and is represented by the letter n. Thus

$$n = Fr/s$$

Since all discussions of elasticity and rigidity have been based upon Hooke's law *ut tensio sic vis*, it is desirable to state some definitions which will avoid confusion later when we come to deal with substances which no longer obey this law.

Within the elastic limit the resistance to distortion is not a function of the time, but as soon as the elastic limit is passed and we have pseudo-plastic flow, this resistance becomes a function of the time. We may, however, still speak of the rigidity provided

that it is the *instantaneous rigidity, i.e.,* the resistance to distortion extrapolated to zero time.

Since

$$\frac{V}{t} = (F - f)\mu r$$

we have

$$\frac{(F - f)rt}{V} = \frac{1}{\mu} = \zeta$$

This quantity ζ is no more a form of rigidity than mobility is a form of elasticity, although the two have been confused. It has never been given a name but it might be called the *consistency* since it is a measure of the resistance to deformation of the plastic substance after the yield value has been exceeded. Consistency is closely analogous to viscosity.

Resilience and Restitution.—Lord Kelvin has defined resilience as "the quantity of work that an . . . elastic body gives back, when strained to some stated limit and then allowed to return to the condition in which it rests when free from stress. . . . In all cases for which Hooke's law of simple proportionality between stress and strain holds, the resilience is obviously equal to the work done by a constant force of half the amount of the extreme force, acting through a space equal to the extreme deflection." Thus, below the elastic limit the resilience is calculable from the coefficient of elasticity and has no relation to flow since no flow has taken place. In order to make the "stated limit" truly comparable for different materials, Lord Kelvin took the extreme resilience which may be obtained by straining the body to the extreme limit within which it can be strained again and again without breaking or taking a permanent set.

There are objections to the use of the term resilience beyond the elastic limit or applying it to substances which do not follow Hooke's law, for the amount of work which the body will give back will depend upon the time that the body is maintained under stress as well as upon the intensity of the stress employed. Furthermore, the condition in which "it rests when free from stress" is somewhat indefinite, due to the elastic after-effect.

The so-called coefficient of restitution is more nearly free from these objections. It gives us a ratio of the energy available for work after a certain time to the total energy expended in pro-

ducing the strain. If two spheres whose velocities in a given direction are u_1 and u_2 impinge on each other, and their velocities after impact are v_1 and v_2, the coefficient of restitution e is defined by the relation

$$e = \frac{v_1 - v_2}{u_1 - u_2}$$

This ratio cannot exceed unity and Newton actually found for steel, 0.55; for ivory, 0.77, and for glass, 0.94. This indicates that at the velocities used a very large percentage of the energy before impact was stored up as elastic deformation in the case of glass, to reappear later in the form of kinetic energy. This does not necessarily imply that all of the remaining energy is expended in flow, for it may be expended in a variety of ways, as for example in producing sound or other vibrations in the material. The coefficient of restitution in plastic bodies must depend to some extent upon their relative velocities, since below a certain velocity the stress may not be sufficient to exceed the yield value, and above another stress which may be much higher, the body will yield by rupture.

The Elastic After-effect.—We have referred to the fact that when pitch, glass, metals, etc., are subjected to shearing stresses above the elastic limit, the material does not recover its elastic deformation at once but only gradually creeps back toward its original position. If this effect, which is so obviously dependent upon the time, is a kind of plastic flow, we have a right to inquire whether the law of plastic flow may apply, *viz.*,

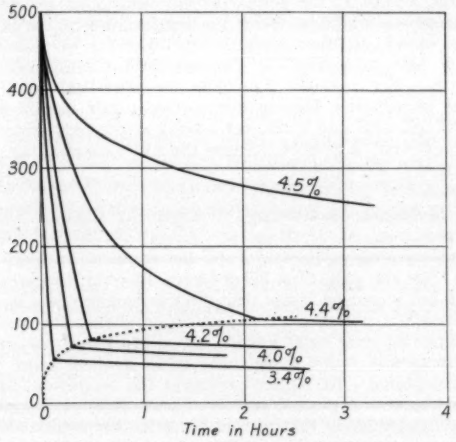
$$v = \mu (F - f) r$$

in which case we should expect the amount of the creep at any instant to be proportional to the excess of the internal stresses above the yield value, or to $F - f$; and in the case of viscous liquids a formula of the same type would apply except that the yield value would be zero.

In plastic solids the internal stresses should never disappear spontaneously but should approach values equal to the yield value of the material. We should, on the other hand, expect the internal stresses brought about by flow to disappear when the material is heated because in the process of annealing the yield value is greatly

lowered. This expectation is neatly verified by the experiments of Rankine.[8] Having strained jellies prepared from gelatin, under a constant stress of 500 grams, he took off stress in such a manner that the deformation was maintained constant. He found that the load fell to a certain value where there was an abrupt break

FIG. 9.



Stress-time diagram for gelatin recovery, after Rankine.

in the curve. This break, shown in Fig. 9, comes at a higher value of the stress the more concentrated the solution. This accords with the experiments of Hyden[9] which show that the yield value in emulsion colloids increases rapidly with the concentration, and in a non-linear manner. It is to be noticed that even after the break in the curve the flow continues although at a greatly diminished rate. This is again evidence of what we have called pseudo-plastic flow.

Trouton and Andrews[10] have made similar experiments with pitch, but no break in the curve is observable, which is evidence that pitch is a viscous liquid.

[8] *Phil. Mag.* [6], **11**, 447 (1906).
[9] "Fluidity and Plasticity," p. 292.
[10] *Proc. Phys. Soc.*, London, **19**, 47 (1905).

Further Studies in the Glow of Phosphorus, and its Extinction in Moist Oxygen. LORD RAYLEIGH. (*Proc. Royal Soc.*, A 726.)—L. and E. Bloch found in 1908 "that if a blast of air was allowed to pass over fragments of phosphorus in a glass tube, the luminosity could be detached or blown off from the surface of the phosphorus, only making its appearance some way downstream." In January, 1914, the author had no difficulty in repeating this experiment. Some years later, however, the result proved very hard to obtain. An arrangement was made by which the temperature of the phosphorus could be varied. It then became clear that the necessary velocity of the air blast was largely dependent on the temperature of the phosphorus. For example, "to blow the glow half-way (8.5 cm.) down the phosphorus, leaving the upstream half dark" requires a velocity of 44, 1.68 and 1 cm. per second at the respective temperatures of 15°, 10° and 4° C., when the blast contains 47 per cent. of oxygen. G. F. S.

The Molecular Scattering of Light in Carbon Dioxide at High Pressures. C. V. RAMAN. (*Proc. Royal Soc.*, A 726.)—In the unsaturated vapor at 30° C. the quantity of light scattered laterally from the path of a beam increased when the pressure was increased, but increased faster than did the density. For example, at 20° C. under a pressure of twenty atmospheres the density was twenty times as great as at normal temperature and pressure, while the scattering was found to be thirty-three times as much as under normal conditions. At higher pressures the scattering outstripped the density to even a greater extent. Under sixty-eight atmospheres these two quantities, in the same units as in the previous statement, were 127 and 940, respectively. Furthermore, with increase of pressure "the polarization of the scattered light becomes sensibly more and more perfect."

The scattering in the saturated liquid and also in the liquid in equilibrium with the vapor becomes enormous in both cases when the critical temperature is approached. In the liquid at 31° it amounts to 35,000. Upon the application of pressure to liquid CO_2 at temperatures below the critical temperature, the scattering sinks as the pressure is made greater, and at the same time the polarization becomes notably more imperfect. In the gas above the critical temperature, as the pressure rises, at first the scattering increases, but it attains a maximum and then diminishes.

Since the molecules of the gas used are anisotropic, the scattering as calculated from the Einstein-Smoluchowski theory must be supplemented by an additional "orientation scattering." When this is included the observed results accord well with the theory except in the vicinity of the critical temperature. G. F. S.

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

SPECTRORADIOMETRIC ANALYSIS OF RADIO SIGNALS.[1]

By Chester Snow.

[ABSTRACT.]

In order to obtain a basis for measuring the interference-producing quality of a radio station, measurements were undertaken at the Bureau of Standards by R. T. Cox to develop a method of spectral analysis of a radiation by means of a receiving circuit whose resonance frequency could be varied through wide limits by varying the capacity in series. A radiation was produced which was regularly repeated, and the effective value of the current in the receiving circuit was measured by means of a hot-wire ammeter. The time interval between the signals was uniform and small compared with the period of the ammeter. In this case the readings of the ammeter, when plotted against characteristic frequency of the circuit, would have the same relative form as if only one signal had been received. The ammeter gave the mean value of the current squared, which was some multiple of that which would have been obtained from a single value, if all were of the same type.

Since the resonance peak of a circuit cannot be made infinitely narrow, the latter will respond not to one wave-length only, but to a considerable range of wave-lengths and in varying degree. The interpretation of the observed current as a function of the characteristic frequency of the circuit requires that we find how the circuit affects the record, in order that the spectral distribution of energy may be derived therefrom.

To do this is the aim of the present article. The problem consists essentially in finding practicable methods of solving a certain integral equation. Four different forms of solution are here obtained.

The first exhibits the solution in the form of a double integral analogous to Fourier's. This form is a solution only when the observed function is given analytically, but is useful as a basis for deriving other forms.

* Communicated by the Director.

[1] Scientific Papers, No. 477, price ten cents.

The second method is based upon the fact that when the nucleus of an integral equation of this type is an even function of the sum or difference of the two variables its corresponding normal functions are trigonometric functions. Harmonic analysis of the nucleus (mechanically or graphically) then amounts to a determination of the characteristic constants. A similar analysis of the observed function has then been shown to lead to a series solution.

The third form gives the solution in terms of differentiations and integrations of the observed function. Like the first two methods it is applicable to cases where the distribution of energy in the spectrum of the wave is discontinuous, and has the advantage that the operations may be performed graphically.

The fourth method consists in representing the observed function by empirical equations of certain simple types, the solution corresponding being easily obtained by subtracting the damping coefficient of the circuit from certain analogous parameters in the simple types of solution used. This method is applicable to the limiting case of the line spectra or undamped waves. It is applied to three different experimental curves.

A COMPARISON OF THE DEOXIDATION EFFECTS OF TITANIUM AND SILICON ON THE PROPERTIES OF RAIL STEEL.[3]

By George K. Burgess and G. Willard Quick.

[ABSTRACT.]

THE Bureau of Standards in continuation of previous work done in studying processes of manufacture of rail steel has completed a coöperative investigation of the effects of titanium and silicon deoxidation on rail steel.

The investigation included the tabulation of data on the manufacture of the steel by the Titanium Alloy Manufacturing Company and the Bureau of Standards, the rolling and inspection of the rails by R. W. Hunt and Company, laboratory tests on 4½-foot sections from the top and bottom ends of 33-foot A rails, which came from the middle ingot of the heats by the Titanium Alloy Manufacturing Company and the Bureau of Standards, and service tests on the remaining 24 feet of these rails in the tracks of the Illinois Central Railroad Company.

Sections of the 4½-foot pieces from the tops of these rails

[3] Technical Papers, No. 241, price ten cents.

were used for the following tests: Horizontal etched sections, White-Souther endurance tests, Stanton repeated impact tests, notched-bar impact tests, tensile tests, sulphur prints, hardness tests, and microscopic examination; and from the bottom ends (24 feet below the top samples) for sulphur prints and hardness tests, tensile tests, notched-bar impact tests, Stanton repeated impact tests, chemical analyses, etched sections, and microscopic examination.

Although it is difficult to draw definite conclusions from the relatively small number of tests on rails from the various heats where slight differences in practice and in chemical analyses introduce variables, the results point to the following general conclusions.

(1) A higher percentage of piped rails come from titanium-treated than from silicon-treated rails, but the time of teeming affects the number of pipes. The greatest number of pipes were in rails from steel treated with the smaller amount of ferrocarbon-titanium per ton, and variations in the amount above this did not seem to affect the pipe.

(2) The titanium-treated rails were harder to break and showed more uniform fractures in the drop test than those treated with ferrosilicon.

(3) The titanium additions compared with the silicon additions had a marked effect in reducing the segregation of carbon at the top of the ingot. This improvement was approximately proportional to the titanium additions but the effect falls off rapidly at the bottom end of the A rails.

(4) Nitrogen determined by the Allen method decreases as the residual titanium in the steel increases. This indicates that less nitrogen is combined with iron and manganese not that the nitrogen has been eliminated, but that it probably is combined with titanium or silicon.

(5) The addition of from eight to ten pounds of ferrocarbon-titanium per ton causes an immediate and appreciable drop in the amount of oxides reducible by carbon, while for additions of more than this amount the oxides reducible by carbon are entirely lacking.

(6) Titanium treatment is shown by sulphur prints to lessen segregation of sulphur, particularly in the drop-test pieces, and in samples from the top ends of the A rails where this segregation is most prevalent in the silicon-treated rails. This condition was

checked by etching specimens in boiling hydrochloric acid which showed streaks in many of the silicon-treated pieces; whereas, the pieces treated with titanium remained practically free from streaks.

(7) Rail sections from the top of the ingots from titanium-treated heats were more uniform in hardness than those from similar positions in silicon-treated heats. The effect had entirely disappeared at the bottom of the ingot.

(8) The results of tensile, impact, and endurance tests did not show as much improvement from the titanium treatment as was expected from the decreased segregation. There was somewhat more uniformity in physical properties at the top ends of A rails from titanium than from silicon-treated heats. At the bottom ends of A rails, not much improvement was shown by titanium treatment.

(9) Steel treated with from eight to ten pounds of ferrocarbon-titanium per ton retains about 19 per cent. of the titanium, and steel treated with from ten to thirteen pounds about 33 per cent.; whereas, the silicon-treated steel retains about 81 per cent. of the silicon. The smaller amount of titanium remaining in the steel treated with from eight to ten pounds of ferrocarbon-titanium per ton is retained in the form of violet inclusions, perhaps, of titanium oxide and some of a lower nitrogen compound of titanium, and for treatments with larger amounts, much more titanium is retained as similar violet inclusions and in addition in the form of orange inclusions, probably a higher nitrogen compound of titanium.

(10) In the titanium-treated steel the sulphide inclusions were more broken up and scattered than in the silicon-treated steel and this effect is dependent upon the retention of titanium in the steel.

A MEASURE OF THE COLOR CHARACTERISTICS OF WHITE PAPER.[1]

By R. E. Lofton.

[ABSTRACT.]

IN attempting to measure the color properties of white papers, use was made at the outset of a single reflection of light from the paper into a spectrophotometer, but it was soon found that the color differences between white papers were so small in most cases

[1] Technologic Papers, No. 244, price five cents.

that these differences could not be readily and accurately determined from a single reflection.

At about this stage of the investigation this bureau purchased a colorimeter designed and built by Prof. A. H. Pfund, of Johns Hopkins University, on the multiple reflection principle. By means of this instrument the color peculiarities of a paper are determined from three or more diffuse reflections from the paper, and its color characteristics are thus very much accentuated.

The color characteristics were determined by measuring the coefficient of diffuse reflection for red (625 $m\mu$ wave-length), green (550 $m\mu$ wave-length), and blue (460 $m\mu$ wave-length) light. The means of getting the three colors of light were three glass filters, transmitting light of the dominant hue as given above, inserted consecutively in the eyepiece tube of the colorimeter, and the diffuse reflection from the paper was matched against the standard for the three colors given.

The color characteristics of twenty-one samples of commercial papers, collected from various sources, were determined, and it was found that all were more or less deficient in the proportion of blue light reflected, and also that all were deficient, but to a much smaller degree, in the proportion of green light reflected.

The twenty-one samples were also matched for color by unaided eye observation by seventeen individuals experienced in color work. There was practically no agreement, however, among the seventeen individuals as to the "whiteness" of the various papers. This circumstance would thus seem to be an effective argument for the substitution of the Pfund colorimeter for the unaided eye as a means of grading white papers for color.

EMBRITTLEMENT OF MALLEABLE CAST IRON RESULTING FROM HEAT TREATMENT.[4]

By Leslie H. Marshall.

[ABSTRACT.]

RECENT investigations have shown that commercial malleable iron is often embrittled by quenching from certain temperatures in the "blue-heat" range. The low shock resistance of such material after hot-dip galvanizing has brought this fact to the front. The present study of the problem showed that the magni-

[4] Technologic Papers, No. 245, price five cents.

tude of this deterioration varied with different samples of iron; the Izod impact test was used as a convenient means for measuring the effect. The embrittlement was limited to a fairly definite range of quenching temperatures. Aging after treatment did not affect the results. The rate of cooling from the blue-heat range was important. If the malleable iron were slowly cooled instead of quenched from these temperatures, the impact resistance was much higher. It was also found that the upper limit of the embrittlement zone lay a few hundred degrees Fahrenheit below the critical point. Quenching from temperatures in this intervening zone increased the impact-resistance of the iron and made it immune to the blue-heat deterioration. The information obtained did not solve the question of the fundamental cause of the embrittlement but did point out a method for eliminating it.

STANDARDS FOR ELECTRIC SERVICE.[8]

[ABSTRACT.]

CIRCULAR 56 on "Standards for Electric Service" is one of the series of papers of the Bureau of Standards on service standards for public utilities and presents a full and exhaustive discussion of the engineering factors involved in the regulation of electric service for light and power, through rules promulgated by authority of public service commissions.

The factors entering into safe, adequate, and satisfactory electric service are proper station operation, a carefully designed distribution system, its erection, care, and maintenance; the metering and measuring apparatus and the means provided for maintaining accuracy of the meters; utilization devices and apparatus suited to the class and kind of current supplied; and general safety of the equipment and system both for operators and the general public.

All the rules of the twenty-two states regulating service are given complete; and, based on the practice of operators and commissions, a full set of rules, suitable for use in the twenty or more states that have not yet adopted service rules, is suggested, while three ordinances for the use of cities desiring to regulate electric service are also given. The suggested rules and ordinances cover the maintenance of lines and station equipment, methods of meter-

[8] Circular No. 56, price sixty cents.

ing and maintenance of meter accuracy, variations in voltage, standard frequency, billing for service and energy used, interruption to service, complaints as to meter errors, testing, and general relations with customers.

The circular is an exhaustive compilation of present-day accepted good practice in all the technical and engineering phases of central station electric service involved in regulation by public service commissions.

SIMPLIFIED PRACTICE RECOMMENDATION NO. 9—WOVEN WIRE FENCING.

[ABSTRACT.]

THE value of simplified practice as a medium for the reduction of industrial waste was again fully demonstrated when the manufacturers of wire fence met with the representatives of distributors and users in a general conference at the Department of Commerce under the supervision of the Division of Simplified Practice, on July 11 and 12, 1923.

A careful survey had been made of the farm, field, and poultry woven wire fence industry by the manufacturers, who presented their findings in detail at the conference. This survey showed the styles of fence produced by the entire fence industry, including catalogue houses and all others; the total number of styles currently produced, and the suggested eliminations.

A cumulative arrangement of sales of the various styles of fence turned out by the several manufacturers was displayed, and of this closely typewritten seven-page list of styles, four pages could be eliminated before 5 per cent. of production was reached. Indeed, the first six pages comprehended but 15 per cent. of production, leaving, on a single page, the styles which covered 85 per cent. of the business done.

The combined efforts of this conference resulted in a reduction from 552 styles of woven wire fence to 69, and a reduction from 2072 sized packages to 138, corresponding to respective eliminations of 87.5 and 93.4 per cent.

Simplified Practice Recommendation No. 9 eliminates all fencing known as farm or field fence made out of Nos. 13, 14, 14½ and smaller gauge wire except the types specifically noted, and provides that no fencing known as poultry fence shall be made of lighter gauge than No. 14½. Fencing made as equiva-

lent to poultry netting is to be so named and of gauge not heavier than 15½. Style is expressed in accordance with regular trade practice, the first number indicating the number of bars and the second the overall height in inches; thus 11–55, an 11-bar fence 55 inches high. American Steel Wire gauge, formerly called Washburn and Moen gauge, is used. Thirty-two and sixteen stays per rod are considered equivalent, respectively, to 6 and 12-inch spacing. Furthermore, it is recommended that rolls of field fence be restricted to 10, 20 and 40 rod lengths, and rolls of poultry fence to 10 and 20 rod lengths.

September 1st was chosen for application to the manufacture of new stocks and "every effort would be made to clear existing stocks of eliminated styles by January 1, 1924." It was further agreed that the recommendation shall be subject to revision semi-annually by conference with the central committee of the industry.

One prominent manufacturer is of the opinion that faithful adherence to Simplified Practice Recommendation No. 9 will mean a reduction of only 6.3 per cent. of the total amount of fence made. This does not necessarily mean that the 6.3 per cent. is indicative of a reduction in the consumption of fence, for the reason that other styles as suggested will be used in place of these special styles which have been eliminated.

Jules Violle.—Not far from Dijon in France is the village of Fixin where a soldier of the First Empire caused to be placed Rude's statue of Napoleon leaving the tomb to put on immortality. It was here that Jules Violle died in September, 1923, at the age of eighty-two years. His activity as a physicist was concerned with such questions as solar radiation, the measurement of high temperatures, the velocity of sound, the dispersion of complex sounds and the mechanical equivalent of heat. For the determination of this fundamental relation he used the ingenious method of Foucault currents developed in a mass of metal moving in a magnetic field. It was he who suggested the delimitation of a standard source of light subsequently adopted by an international conference in 1884. This was a unit surface of melted platinum at its point of solidification. While such a definition is clear from the point of view of theory, it may be criticized from other angles. Friedrich Kohlrausch desired to oppose the adoption of this definition at the conference, but refrained on account of his lack of facility in speaking French.

Violle in 1897 became the successor of Fizeau in the Academy of Sciences. G. F. S.

NOTES FROM THE U. S. BUREAU OF CHEMISTRY.*

HAZARD OF FLAMMABLE DUST SHOWN IN A RECENT EXPLOSION OF ALUMINUM POWDER.[1]

By David J. Price and Robert M. Baker.

[ABSTRACT.]

AN explosion of aluminum-bronze powder in a printing establishment in Richmond, Virginia, recently caused the death of an employee and wrecked a bronzing machine and its equipment. The explosion originated in an exhaust duct from a cyclone dust collector, and propagated to the vacuum chamber in the bronzing machine, the dust-collecting equipment and the machine being in operation at the time. An investigation indicated that the explosion was not caused by any defect in the machine, but by an electric wire being in contact with the exhaust duct containing an explosive dust-air mixture.

EXPERIMENTAL PRODUCTION OF STRAW GAS.[2]

By Harry E. Roethe.

[ABSTRACT.]

IN 1921 the Bureau of Chemistry of the United States Department of Agriculture undertook a study of the production of gas from straw and similar material now often wasted on American farms.

Only one of the types of equipment available for straw-gas production, and that not the most improved one, and only a few of the many kinds of material which may be carbonized were used in these tests. The experiments, however, were extensive enough to show that the type of equipment employed in these tests is not practicable as a farm unit, even though the gas produced can be satisfactorily used for heating, lighting, and stationary power purposes.

* Communicated by the Chief of the Bureau.

[1] Published in *Chem. Met. Eng.*, 29 (Nov. 12, 1923) : 878.

[2] Issued as U. S. Dept. Agr. Bul. 1203, Nov., 1923.

PROPERTIES OF DYED MATERIALS.[3]

By H. Wales.

[ABSTRACT.]

EVER since the discovery of artificial colors, attempts have been made to find some relationship between the color and the chemical constitution. For some classes of dyes theories have been worked out with fair success. In practically every case, however, the "color" has been determined by means of the position of the absorption band or bands as determined with a spectroscope.

A study of the absorption spectra of light reflected from dyed materials was made in the Bureau of Chemistry. The results showed that the reflection spectra more nearly explain the variations in color between two dyes than the transmission spectra of the solutions.

Dyeings made on wool, paper and gelatin indicated that the dye was present as a solution in these materials.

Fluosilicic Acid.—An extensive series of experiments by C. A. JACOBSON, of the University of West Virginia (*J. Phys. Chem.*, 1923, **27**, 761–770), leads to the conclusion that fluosilicic acid is a non-volatile acid like carbonic and sulphurous acids. Under ordinary conditions, it cannot exist in the vapor state but completely decomposes into hydrofluoric acid and silicon tetrafluoride.

J. S. H.

Post-fixation Development. HENRY LEFFMANN (*Trans. Wagner Free Inst. Sci.*, 1923, **10**, 7–14) has made an extensive study of post-fixation development. A 5 to 10 per cent. solution of sodium thiosulphate ("hypo") may be used for fixation prior to development. A 2 per cent. solution of potassium cyanide apparently destroys all traces of the latent image. The developing solution is prepared by mixing two solutions immediately prior to use. Each of these solutions contains sodium sulphite, one also contains a mercuric salt, preferably the bromide; the other also contains an organic developer, preferably metol or a mixture of one part metol and three parts glycin. The visible image is produced by deposition of metallic mercury on the latent image. Since mercury gradually evaporates even at atmospheric temperature, the image may thereby become invisible, but can then be restored by treatment with the developing solution. Silver salts cannot replace mercuric salts in the developing solution.

J. S. H.

[3] Published in *J. Am. Chem. Soc.*, **45** (Oct., 1923) : 2420.

NOTES FROM THE U. S. BUREAU OF MINES.*

GRAPHITES FOR BRASS-MELTING CRUCIBLES.

By R. T. Stull.

PREVIOUS tests on bond clays by the bureau had determined that American clays can be used successfully in graphite crucible manufacture and service. The next step was to determine the value of American graphites as compared with the foreign. The final tests were carried out at the plant of the Detroit Lubricator Company, through the courtesy of Mr. G. B. Duffield. The crucibles, as previously, were made at the plant of the Vesuvius Crucible Company, Swissvale, Pennsylvania, from a formula compiled by the Bureau of Mines and under the supervision of bureau engineers. The results show that Alabama graphite bonded with the American clays gave superior service, a service at least equal to the commercial crucibles of the same class which have been sold on the open market. Ceylon graphite, which is considered by many manufacturers to be best for crucible work, was third in the list of tests, and Canadian graphite, which had been recommended very highly because of its structure, was last. Further details are given in Serial 2542 of the bureau.

MINE TIMBER IN PENNSYLVANIA COAL MINES.

By Harry E. Tufft.

THE present annual consumption of mine timber by the coal-mining industry of Pennsylvania probably exceeds 100,000,000 cubic feet annually. The average cost of round timber in the anthracite region in 1905 was, according to the U. S. Forest Service, 6.6 cents per cubic foot, and $15 per 1000 board feet for sawed timber. The present cost has advanced to 27.5 cents per cubic foot for round timber, delivered to the mine, of which cost 57.3 per cent. represents freight charges. In the anthracite region, twenty to twenty-five years ago, the best grades of white and red oak, chestnut, and pitch pine timber could be obtained locally. The major part of the timber used was hardwoods. At

* Communicated by the Director.

present perhaps 75 per cent. or more of the timber used in the anthracite region is softwoods, which is largely shipped in from the South. The average timber now being used is much inferior to that used twenty years ago.

In the bituminous districts of Pennsylvania, mine timber is becoming more and more difficult to obtain. Sawed lumber such as mine car plank, brattice board, stopping, and wooden rails, are now largely obtained from the southern states. Round timbers, such as props, ties, posts, and caps, are obtained partly within the state, but at distances of one to several hundred miles from the mine.

On the basis of figures supplied by operators of bituminous mines, of western and central Pennsylvania, representing a combined output of approximately thirty-seven million tons annually, for the amount and costs of timber delivered to these mines, and taking the corresponding productions for the same periods, the average annual cost of the delivered timber is found to be 5.5 to 7.1 cents per ton of coal mined, for different operators, with a general average of about 6.5 cents. The corresponding consumption for the above mines is 0.25 to 0.44 cubic foot per ton mined, respectively, for different operators, with a general average of 0.30 cubic foot per ton mined.

In 1905 the average cost of round timber was 3.5 cents per cubic foot, and that of the sawed timber was $17.39 per 1000 board feet. Split prop timber now costs 14 cents and round prop timber 18½ cents per cubic foot, or five times as much as in 1905. Also, the cost of sawed timbers has increased from the average of $17.39 per 1000 board feet, to approximately $40, making an increase of 2.5-fold compared with 1905. Further details are presented in Serial 2546.

DETERMINATION OF FINENESS OF PULVERIZED COAL.

By W. A. Selvig and W. L. Parker.

As the result of experiments conducted by the Bureau of Mines in coöperation with commercial coal laboratories, and the Bureau of Standards, a method for determination of fineness of powdered coal by hand sieving on United States Sieve Series Sieves Nos. 100, 140, and 200 has been standardized and tested by twelve coöperating laboratories.

For routine testing a method of machine sieving has been

standardized and tested by nine coöperating laboratories. Due to differences of sieving action, which may occur with different mechanical-sieving devices, it is recommended that the hand-sieving method be adopted as standard; and if machine-sieving devices are used, the results obtained should be compared with those obtained by hand sieving, in order to see whether the sieving action is the same.

Considerable variation in sieving values may occur between sieves which conform with the specifications of the United States Standard Sieve Series—these differences between two sieves may amount to as much as 6 per cent.

The same operator, in duplicate tests by the hand-sieving method, using the same sieves, should check within 1 per cent. in all sizes. Different operators using different sieves should check within 3 per cent. on the through 200 mesh when the sieving value correction for the sieve used, as determined by the Bureau of Standards, is applied. Until such time as standard material is available for determining sieving value corrections for the Nos. 100 and 140 sieves, it is not possible to specify check limits, for different operators using different sieves, for the material sieved on the Nos. 100 and 140 sieves. The detailed results are presented in Serial 2545.

SOLUBILITY OF FINELY DIVIDED ROCK DUSTS IN WATER, KEROSENE, AND ALCOHOL.

By W. M. Myers.

IN order to determine the rate of solution during definite periods of time, the effects of different liquid collecting mediums were investigated on two dusts. The liquids used were (1) pure distilled water, (2) water-white kerosene, free from alkali and acid; and (3) 95 per cent. ethyl alcohol. The rate of solution of two typical dusts was investigated; one was that produced in working Bedford limestone, and therefore practically pure calcium carbonate, the other was a highly siliceous dust formed by mining operations in the siliceous cherts of the Tri-state lead and zinc district of Missouri, Oklahoma, and Kansas.

The rate of solution of 5 and 50 mg. quantities of these dusts in 150 c.c. of the liquids was determined over periods varying from one to twenty-eight days. The impinger generally used 150 c.c. of liquid for collecting a dust sample, and this volume was therefore adopted. The loss due to solution was found by filter-

ing the liquid containing the dust through a specially prepared Gooch crucible, by which the weight of the undissolved dust was found. The weight of the dissolved material was determined by difference. The efficiency of the Gooch crucible for filtering such fine particles was determined and found to be approximately 100 per cent. On account of the unavoidable weighing error, the use of the Gooch crucible introduces a possible analytical error which may approach a maximum plus or minus 0.7 mg.

The results showed that the solubility of these dusts in distilled water is relatively high and the rate of solution is rapid. This would be sufficient to produce serious error in any determination of atmospheric dust where water is employed as a collecting medium. The dusts are representative of the two most common types produced by mining, quarrying, stone dressing, and other rock-breaking operations.

The composition of the container, whether it be of ordinary glass, pyrex glass, or platinum, seems to have little effect upon the solubility of the dusts. While some alkalies may have been freed by solution of the ordinary glass, the rate of solution of these particular dusts does not appear to have been accelerated.

There is no evidence of any solution of either dust in kerosene during any period, as is shown by tests 4 and 7.

There is no solution of siliceous dust in 95 per cent. alcohol. Limestone dust displays come solubility in 95 per cent. alcohol, probably due to the water content; but this would not be sufficient to introduce a serious error.

For convenience in analysis it is essential that the liquid be miscible in water. The samples collected in kerosene must be diluted and filtered with the same liquid. This laborious and unpleasant operation makes the use of kerosene objectionable.

As the solubility of finely divided dusts in water is excessive, and sufficient to cause serious error in the determination of the amounts of dust present in the atmospheres of mines and other industries where it is essential to have accurate information, in order to ascertain the hazard to the health of workers exposed to these dusts, the substitution of a liquid which would have no solvent action on the dusts would be advisable. Properly denatured alcohol should be an inexpensive and satisfactory liquid for this purpose in many instances. Further details will be found in Serial 2548.

THE FRANKLIN INSTITUTE.

(Proceedings of the Stated Meeting held Wednesday, December 19, 1923.)

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, December 19, 1923.

MR. W. C. L. EGLIN, Vice-president, *in the Chair.*

The Board of Managers submitted their report. The report recorded the election of the following Resident Members:

Peter Abrams, Esq.,
Williams, Brown and Earle,
Philadelphia, Pennsylvania.

J. P. Goheen, Esq.,
Secretary,
Brown Instrument Company,
Philadelphia, Pennsylvania.

W. M. Irish, Esq.,
Vice-president and General Manager,
Atlantic Refining Company,
Philadelphia, Pennsylvania.

William A. Johnson, Esq.,
Williams, Brown and Earle,
Philadelphia, Pennsylvania.

William St. Clair, Esq.,
2345 North Carlisle Street,
Philadelphia, Pennsylvania.

Henry F. Sanville, Esq.,
Consulting Engineer,
1015 Chestnut Street,
Philadelphia, Pennsylvania.

E. V. Schafer, Esq.,
Automatic Fuel Saving Company,
Philadelphia, Pennsylvania.

James E. Wilson, Esq.,
John Wanamaker,
Philadelphia, Pennsylvania.

the following Non-resident Member:

Francis B. Vogdes, Esq.,
Research Worker,
General Electric Company,
Schenectady, New York;

and additions to the library by gift, 11 volumes, 35 pamphlets, and by purchase 25 volumes.

The Committee on Nominations (Messrs. Franklin, Sanborn, and Morgan) appointed by the President in accordance with a resolution passed at the Stated Meeting held November 21, 1923, presented the following list of nominees to be voted for at the annual election to be held on Wednesday, January 16, 1924.

FOR PRESIDENT (to serve one year) W. C. L. Eglin.

FOR VICE-PRESIDENT (to serve three years) Gellert Alleman.

FOR VICE-PRESIDENT (to serve two years) C. C. Tutwiler.

FOR TREASURER (to serve one year) Benjamin Franklin.

FOR MANAGERS (to serve three years) Charles E. Bonine, Walton Clark, Charles Day, Clarence A. Hall, George A. Hoadley, Lawrence T. Paul, James S. Rogers and Haseltine Smith. On motion, duly seconded, the nominations were closed.

The Chairman then introduced W. F. G. Swann, A.R.C.S., D.Sc., Professor of Physics, University of Chicago, Chicago, Illinois, who presented the paper of the evening on "The Structure of the Atom."

The speaker referred to the fundamental entities and radiations associated with the modern theory of the atom. He discussed the electron, the proton and the radioactive radiations and illustrated his remarks by lantern slides. He also discussed the bearing of spectral and radioactive phenomena on the theory of atomic structure and referred to the work of Thomson, Rutherford, Aston, Bohr and Sommerfeld in connection with the development of this theory.

The Chairman extended the thanks of the Institute to the speaker for his highly interesting paper and the meeting adjourned.

R. B. OWENS,
Secretary.

COMMITTEE ON SCIENCE AND THE ARTS.

(Abstract of Proceedings of Stated Meeting held Wednesday, December 5, 1923.)

HALL OF THE INSTITUTE,
PHILADELPHIA, December 5, 1923.

MR. W. H. FULWEILER, *in the Chair.*

The following reports were presented for first reading:

No. 2799: Gear Tooth Grinding Machine.
No. 2814: Elliott Deaerator.
No. 2819 and No. 2820 } Franklin Medal.

R. B. OWENS,
Secretary.

MEMBERSHIP NOTES.

ELECTIONS TO MEMBERSHIP.

(Stated Meeting, Board of Managers, December 12, 1923.)

RESIDENT MEMBERS.

MR. PETER ABRAMS, Treasurer and General Manager, Williams, Brown and Earle, Philadelphia, Pennsylvania.

MR. J. P. GOHEEN, Secretary, Brown Instrument Company, Philadelphia, Pennsylvania.

MR. W. M. IRISH, Vice-president and General Manager, Atlantic Refining Company, 260 South Broad Street, Philadelphia, Pennsylvania.

MR. WILLIAM A. JOHNSON, Vice-president, Williams, Brown and Earle, Philadelphia, Pennsylvania.

MR. WILLIAM ST. CLAIR, 2345 North Carlisle Street, Philadelphia, Pennsylvania.

MR. HENRY F. SANVILLE, Consulting Engineer, 1015 Chestnut Street, Philadelphia, Pennsylvania.

MR. E. V. SCHAFER, Combustion Engineer, Automatic Fuel Saving Company, Philadelphia, Pennsylvania.

MR. JAMES E. WILSON, Optician, John Wanamaker, Philadelphia, Pennsylvania.

NON-RESIDENT MEMBERS.

MR. FRANCIS B. VOGDES, Research Worker, General Electric Company, Schenectady, New York.

CHANGES OF ADDRESS.

MR. C. A. HALL, 7951 Winston Road, Chestnut Hill, Philadelphia, Pennsylvania.

PROF. ERNEST E. JOHNSON, 5850 North Sixth Street, Philadelphia, Pennsylvania.

MR. ARTHUR KNAPP, Box 1902, Philadelphia, Pennsylvania.

MR. ELISHA LEE, General Manager, Pennsylvania Railroad Company, Room 909, Pennsylvania Station, Pittsburgh, Pennsylvania.

MR. SIMON MILLER, 1530 Locust Street, 5-B, Philadelphia, Pennsylvania.

MR. C. H. QUINN, Palace Hotel, San Francisco, California.

MR. F. E. WHITNEY, 6407 North Sixth Street, Oak Lane, Philadelphia, Pennsylvania.

NECROLOGY.

Mr. J. Stanford Brown, Black Hall, Connecticut.

Dr. Samuel P. Sadtler, 210 South Thirteenth Street, Philadelphia, Pennsylvania.

Mr. Henry W. Scattergood, 530 Land Title Building, Philadelphia, Pennsylvania.

Mr. J. A. Wiedersheim, 1232 Chestnut Street, Philadelphia, Pennsylvania.

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BOOK REVIEWS.

THE VAULT OF HEAVEN: AN INTRODUCTION TO MODERN ASTRONOMY. By Sir Richard Gregory, Hon. D.Sc., F.R.A.S. vii–202 pages, 61 illustrations, 12mo. New York, E. P. Dutton and Company, 1923. Price, $2.50 net.

> "These earthly godfathers of heaven's lights
> That give a name to every fixed star,
> Have no more profit of their shining nights
> Than those that walk and wot not what they are."

Was the cynical Biron right? Is the contemplation of the "Vault of Heaven" as impressive and enjoyable to those who know nothing of its nature as to the expert astronomer? Whatever may be the answer, mankind will always be seeking information concerning celestial objects. Astronomy began doubtless as soon as man became fairly conscious of his environment. We know, indeed, that "star-gazing" was an occupation of the priests on the plains of Mesopotamia in the morning twilight of civilization. The original of "Twinkle, twinkle, little star" has not been yet found in cuneiform or hieroglyphic texts, but the records in those languages abound in references to celestial phenomena. Socrates, on one occasion, discussed with his disciples the value of astronomy, and, characteristically, deprecated the commendation of its several practical applications, laying stress on its ennobling influence. Yet the sky on a clear, cold night probably awakens a feeling of awe rather than of pleasure. We are not astonished that sinister influences have been and still are ascribed to the stars. Science, in the strict sense in which we understand the word to-day, was developed in ancient times only among the Greeks, and literature of the golden age of that nation constitutes the real beginnings of astronomy. Cumont has shown how stoutly the Greek philosophers opposed the oriental superstitions concerning the influence of the stars on human destiny, but the mass of the people were receptive to the views, and even in these days of enlightenment, astrology has many converts and many who cater to the believers.

Sir Richard Gregory's book is a second edition of a book published some years ago, but has been so completely revised as to make it a new and original

issue. It presents in compact and attractive form the state of modern astronomy, and discusses some of the moot points. It is eminently suited to the general reader who desires information concerning the ascertained facts of the universe, is interested in the problems of "Whence and Whither" and curious to know if astronomy has yet discovered any evidence of life on other worlds. The author has skilfully combined the known facts of importance with occasional excursions into the inferential realms, leaning, as most of us do, towards the belief that the earth is not the only abode of living organisms. It is, however, pointed out that all such speculations are so far without definite result. It is very gratifying to note that in dealing with the now famous—or might one say, notorious—"canals" of Mars, our author calls attention to the fact that the word should be "channel," that being the proper translation of Schiaparelli's term "canale." As Gregory says, "canal" suggests artificial construction. There is little doubt that some of the vogue of Martian assumptions has been due to the misleading term. In a chapter on "Celestial Evolution," the more important theories of the extent and nature of the universe are considered. The attractive suggestion that the "Milky Way" is the bounding structure of our universe, and that the spiral nebulæ are other universes is noted as not yet established. A very large number of excellent illustrations add greatly to the readableness and usefulness of the book, and show what service photography and spectroscopy have done for astronomy. An illustration on page 73, a diagrammatic explanation of solar and lunar eclipses, suggests a query which should be specifically answered in works on popular astronomy. The drawing shows, as is usual in such works, the orbit of the moon convex to the sun in one-half of its extent and concave in the other half. Young, in his work on astronomy (1888, page 151), says that the orbit of the moon is "everywhere concave to the sun." It is hardly likely that so distinguished and experienced an astronomer would be wrong in a statement so positively expressed, yet it is worth while for astronomers to give attention to the matter. It seems difficult—at least it is to the reviewer—to conceive a curve always concave to the sun and yet representing the moon's path. Young gives a drawing illustrating his statement, but it does not make the matter perfectly clear. If Young's statement is correct, then the moon goes round the sun, as well as round the earth. As a matter of fact the earth and moon move around a common centre of gravity which is within the earth's mass.

The mechanical execution of the book is excellent, the numerous photographs are of the best, the type is clear and paper of high quality. The text is excellently written, making a very attractive, interesting and serviceable introduction to the facts of astronomy and the methods of its progress.

HENRY LEFFMANN.

WEATHER PROVERBS AND PARADOXES. By W. J. Humphreys, Ph.D., U. S. Weather Bureau. viii–125 pages, 16 plates, 2 illustrations in text, 12mo. Williams and Wilkins Company, Baltimore, 1923. Price, $.150 net.

Intended as a popular treatise, the phenomena of the weather are presented in this book in much lighter vein than in the author's well-known and authoritative "Physics of the Air." The weather has always been an acceptable topic in dull company or in passing greetings, and the profound influence which

weather conditions have upon human beings has given rise to an immense mass of folk-lore much of which is intended to aid in forecasting. Some years ago the U. S. Weather Bureau published a large collection of "indications" as gathered from the mass of the people, especially farmers and sailors. Doctor Humphreys, like Silas Wegg, drops into poetry occasionally, and the humorous vein in which most of this verse is written, reminds the reviewer of a bit of doggerel produced by a Philadelphia humorist in the early period of the Weather Bureau's activity. Prognostications were furnished to the press under the title "Probabilities." The bureau in its early days was not by any means always accurate, was dubbed "Old Probabilities," and a great deal of fun poked at it. The local humorist wrote a few verses of which one will suffice.

"Who predicts rain, and makes us fellows
Rush down town with big umbrellas,
And then clears up so as to sell us?
Old Probabilities."

Doctor Humphreys has produced a very readable volume, vividly illustrated and well adapted to show to the general public the extent and value of meteorology. In the second part he adopts a somewhat Chesterton attitude and sets forth a number of apparent paradoxes. In these paragraphs fundamental and important weather and climatic phenomena are explained under more or less startling headlines such as "The closer the Sun, the colder the season." It is, however, promptly explained that this rule applies only to the northern hemisphere. It seems to the reviewer that in some cases there is a little too much "urge" in seeking striking phrases, but this is a minor point and one on which opinions will differ. The book is adapted to spread correct views in a field in which there has been too much left to the ignorant and superstitious.

HENRY LEFFMANN.

AIDE-MÉMOIRE POUR L'INDUSTRIE CAOUTCHOUC ET DES MATIÈRES PLASTIQUES. By A. D. Luttringer, D.Sc. Paper, 225 pages, illustrations, 8vo. Paris, Cillard, 1923. Price, 32 Francs net.

The enormous growth of the rubber industry in recent years, due, of course, most to the popularity of the motor vehicle, has given rise to economic and scientific problems of complexity and great importance. English is the only language that uses the term "rubber" derived from the old and almost sole use of the material for erasing lead pencil marks. Priestley was the introducer of the term. To other nations the material is known as "caoutchouc." The book in hand presents a large amount of information on the industry of rubber and other plastics, summaries of methods of analysis, and a large amount of tabular matter, both that bearing directly on the industry and concerning the calculations of the shop, counting-house and laboratory. In a table of the relative values of the usual coins of account of the principal nations, the franc is rated at 6.18 to the dollar. This is either a typographic error or a calculation based on the exchange value at the time the book was published. If the latter, it is an unwise procedure. Such a table should give equivalences in par. The par value of the French franc is a trifle less than one-fifth of a dollar. The growth of rubber production is vividly shown by the statistics of the

amounts sent into the markets since 1900. In that year, the world's production was nearly 54,000 tons, more than half of which came from Brazil. In 1922, the production was close to 380,000 tons, of which Brazil furnished less than 22,000. The increase is, as is well known, almost entirely plantation product. Of the 1922 output, America took 75 per cent., Great Britain less than 3 per cent., France and Germany about 7 per cent.

By compact arrangement and condensed text, although not sacrificing clearness, Doctor Luttringer's book makes a very acceptable contribution to the literature of the great and growing industry of plastic materials. The portions devoted to gutta percha are especially acceptable as this material has lost a great deal of prominence in the great expansion of the use of rubber. A brief introduction is given by Doctor Haller of the School of Physics and Industrial Chemistry. Being a French book, there is, of course, no index.

HENRY LEFFMANN.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS. Report No. 175, Analysis of W. F. Durand's and E. P. Lesley's Propeller Tests. By Max M. Munk. 14 pages, diagrams, quarto. Washington, D. C., Government Printing Office, 1923. Price, five cents.

This is a critical study of the results of propeller model tests with the view of obtaining a clear insight into the mechanism of the propeller action and of examining the soundness of the physical explanation generally given. The nominal slipstream velocity is plotted against the propeller tip velocity, both measured by the velocity of flight as a unit. Within the range corresponding to conditions of flight, the curve thus obtained is a straight line. Its inclination depends chiefly on the effective blade width, its position on the effective pitch. These two quantities can therefore be determined from the result of each propeller test. Both can easily be estimated therefrom for new propellers of similar type. Thus, a simple method for the computation of propellers suggests itself.

The slip curve mentioned is not a straight line along its entire length. At a small relative velocity it is bent up, because the lift curve of the blade sections used is bent up that way at small lift coefficients. At a certain high relative tip velocity the slip curve shows a break and runs then straight again, but at a different slope. The slope is increased so that at zero advance the propeller develops a larger thrust than could be expected from the magnitude of the thrust in flight.

PUBLICATIONS RECEIVED.

Weather Proverbs and Paradoxes. By W. J. Humphreys, Ph.D. 125 pages, plates, 12mo. Baltimore, Williams and Wilkins Company, 1923. Price, United States, Canada, Cuba, Mexico, $1.50; other countries, $1.75.

Marine Products of Commerce. Their acquisition, handling, biological aspects and the science and technology of their preparation and preservation, by Donald K. Tressler, Ph.D. 762 pages, illustrations, 8vo. New York, The Chemical Catalog Company, Inc., 1923. Price, $9.

Aide-mémoire pour l'Industrie du Caoutchouc et des Matières Plastiques à l'Usage des Ingénieurs, Chimistes, Praticiens, Directeurs et Contremaitres

d'Usines. Par A. D. Luttringer, preface de A. Haller, membre de l'Institut. 225 pages, illustrations, 12mo. Paris, A. D. Cillard, 1923. Price, 32 Francs.

Leçons sur les Fonctions Uniformes a point singulier Essentiel Isolé. Par Gaston Julia. Rédigées par P. Flamant. 152 pages, 8vo. Paris, Gauthier-Villars et Cie., 1924. Price, 15 Francs.

Physik der Erdbebenwellen. Zusammenfassung der Arbeitswege und der Ergebnisse von Prof. Dr. Carl Mainka. 156 pages, illustrations, plate, 8vo. Berlin, Gebrüder Borntraeger, 1923. Price, $2.20.

Projective Geometry with Applications to Engineering. By Peter Field. 98 pages, illustrations, 12mo. New York, D. Van Nostrand Company, 1923. Price, $2 net.

Notions sommaires de Géométrie Projective a l'Usage des Candidats a l'École Polytechnique. Par Maurice d'Ocagne. 25 pages, 8vo. Paris, Gauthier-Villars et Cie., 1924. Price, 3 Francs.

Elektrische Temperatur-Messgeräte. Von Dr.-Ing. Georg Keinath. 275 pages, illustrations, 8vo. Munich, R. Oldenbourg, 1923. Price, in paper, $2.40.

Arsenic Calcium Arsenate and the Boll Weevil. Articles and addresses by Howard W. Ambruster. 42 pages, 8vo. New York, the Author, 1923. Price, fifty cents.

The Vault of Heaven. An introduction to modern astronomy by Sir Richard Gregory. 202 pages, illustrations, 12mo. New York, E. P. Dutton and Company, 1923. Price, $2.50.

National Advisory Committee for Aeronautics: Technical Notes, No. 166, Determination of Climbing Ability, by H. Blasius. 16 pages, diagrams, quarto. No. 167, Wind-tunnel Tests of Five Strut Sections in Yaw, by Edward P. Warner. 7 pages, diagrams, quarto. No. 168, Experiments with Fabrics for Covering Airplane Wings, to Determine Effect of Method of Installation, by A. Pröll. 39 pages, diagrams, quarto. No. 169, Air Resistance Measurements on Actual Airplane Parts, by C. Wieselberger. 11 pages, diagrams, quarto. Ninth Annual Report, for the Fiscal Year Ended June 30, 1923. 56 pages, quarto. Washington, Committee, 1923.

The Electrical Conductivity of Sulphur on Which X-rays Fall. L. GREBE. (*Zeit. f. Phys.*, 17, p. 295.)—The conductivity of this excellent insulator increased to about 100 times its normal amount when X-rays fell on it. There was a linear relation between the applied voltage and the current traversing the sulphur, but the straight line showing the connection of these two quantities seems to indicate that no current at all would flow when the voltage is below 52. The current was found to be proportional to the intensity of the incident beam. A change in the hardness of the rays produced change in the conductivity of the sulphur and also in the conductivity of air. In these two insulators the ratio of the conductivities is independent of the wave-length of the rays. Monoclinic sulphur has a greater conductivity than the rhombic or common form whether under ordinary conditions or illuminated by X-rays. G. F. S.

CURRENT TOPICS.

Silica Glass.—Among the many products made available by the perfection of the electric furnace, scarcely any are so peculiar in properties and serviceable in certain directions as the glass made from pure silica. Silicates in the form of transparent masses have been familiar for many centuries, but the direct melting of silica itself was not commercially possible until electric current became available at reasonable rates. Advance sheets of the report on the mineral resources of the United States for 1922 give, among other data, considerable information as to the silica-glass industry in this country. The text was prepared by F. J. Katz, and is issued by the U. S. Geological Survey as pamphlet II.21, "Silica in 1922," much of the manufacturing detail being furnished by F. L. Hess.

Two important differences are noted between common glass and silica glass. The latter bears sudden, extreme changes of temperature and transmits a large proportion of ultra-violet radiation. Vessels of silica glass can be dipped when red-hot into cold water without cracking. On comparing two sheets, one of common glass and the other of quartz glass, both quite transparent to the eye, it will be found that the common glass is as opaque to ultra-violet light as a piece of cardboard. The same relative opacity is noted with mica, celluloid, gelatin and many other transparent materials.

In the practical production of silica glass (generally termed "quartz glass") two grades are familiar: Transparent and translucent. The latter may be almost opaque to ordinary light. The opacity is usually due to gas bubbles. In the manufacture of this form a good grade of quartz sand is satisfactory, but for the transparent form a carefully selected and pure material in large pieces must be used. High-grade Brazilian pebble is generally used. The cost of the product is seriously enhanced by the fact that at the temperature of fusion considerable loss from volatilization occurs. It is stated that five pounds of quartz can be fused in twenty minutes in the electric furnace, but about one-fifth of the material will be lost in that time. This is not of very great moment in the cheaper grades, but dealing with high-class quartz, the loss is of great significance.

The first quartz glass articles were all handmade, and this method is still followed in making crucibles, beakers and similar ware. Tubing and rods are now made by machinery. At the laboratory of the General Electric Company at Lynn, Massachusetts, under supervision of Dr. E. R. Berry, who has been seven years experimenting in this line, an extremely clear glass is made. Rods and tubes twenty-six feet long have been made. Much difficulty has been experienced in getting skilled men for this work. When quartz is at the melting point the

light is dazzling, dark goggles must be used and a dark glass plate also interposed. Little of that part of the mass which is not incandescent can be seen, the heat must be interrupted from time to time, and the article allowed to cool in order that the progress of the work may be examined. In making tubes for quartz mercury-arc lamps, now so extensively used, it is necessary that the quartz be welded with a glass that can be worked at a lower temperature. This is accomplished by a mixture of quartz and pyrex glass graded so that the proportions change from pure quartz to pure pyrex. Quartz tubing several inches in diameter and in complex coils is now made for industrial uses. The high index of refraction and transparency to ultra-violet radiation are two qualities which will be of great value in astronomy and microscopy and Doctor Berry hopes to obtain blocks suitable for telescope lenses. Quartz mercury-arc lamps are used in sterilizing water in the tanks of public bath-houses. It is stated that excellent results have been obtained by this method. Application has also been made of the curative effect of ultra-violet rays. The writer of this note knows of a case in which a rather obstinate dry tetter has yielded quite markedly to a few seconds' occasional exposure to ultra-violet light.

In the analytic laboratory quartz dishes and crucibles have been useful as a substitute for platinum, but, unfortunately, they are unavailable in some operations, and the analyst has still to bear the burden that the fashionable use of platinum imposes. H. L.

Mineral Production in the United States in 1922.—Advance sheets of the official report on the "Mineral Resources of the United States" for 1922 have been lately distributed, giving data on several subjects. In a previous issue of this JOURNAL, the data in regard to platinum and its associates were given. Data are now at hand concerning silica production (by F. J. Katz), mica (by B. H. Stoddard), lime and slate (by G. F. Loughlin and A. T. Coons), barytes and derivatives (by G. W. Stose) and secondary metals (by J. P. Dunlap).

The production of mica in 1922 was somewhat greater than in the previous year. Deposits of white mica (muscovite) of commercial value are found only in pegmatite, an igneous rock. Mica deposits not furnishing sheets of sufficient size are utilized for "scrap." The production of sheet mica in the United States in 1922 amounted to 539 short tons; of scrap, 6641 tons. Both classes of product have many uses, among which the manufacture of insulators for electric apparatus is very important. For some purposes the American mica is not suitable, and reliance must be had upon mines in Brazil and India.

As with other products, the 1922 production of lime and slate exceeded that of 1921. Pennsylvania, which has long held first rank in production, was passed by Ohio in 1922. Large amounts of lime are used in construction work, but about one-half the Pennsylvania

output finds application in chemical manufacture. Agricultural use is, of course, a large item. In slate quarrying, the labor problem has been serious. Much of the labor that left the quarries to enter the army did not return after the armistice. The location of the quarries in the northeastern section of the country renders shipment to other points often quite expensive. Efforts have been made in Pennsylvania to establish schools for instruction in methods of slate-quarrying and also to devise and install machinery.

Barium production in the United States in 1922 amounted to 155,000 short tons. The principal compound is barytes (barium sulphate) which is used in paints and as a filler in rubber goods, linoleum, oil cloth and glazed paper. It forms an inert base on which dyes may be precipitated, and has been used in making bricks for X-ray laboratories on account of opaqueness of it to these rays. About 80 per cent. of the domestic output of crude barium ores was from Missouri and Georgia. A limited amount of the output goes into the manufacture of barium sulphide used as depilatory. Barium sulphate is used to coat the stomach in order to outline it by means of a substance opaque to X-rays so as to permit diagnosis of conditions of that viscus. As barium sulphide is very poisonous and barium sulphate not, several fatal cases have occurred by druggists dispensing the former when the latter was intended.

"Secondary metals" are materials from scrap, drosses, skimmings and sweepings. The reports of the U. S. Geological Survey include data on copper, zinc, tin, lead, antimony, aluminum and nickel. The collection of waste in many industrial fields has now become a well-organized and equipped business, far removed from the methods of the old "junk" dealer. Much information on the subject of the collection and use of secondary metals is given in the pamphlet in a reprint of an article by W. M. Corse, chairman of the division of research extension of the National Research Council. One of the most important lines of recovery is that of tin. No domestic primary source of this metal was indicated in 1922 returns, although this country consumes more than half of the world's output. The recovered tin amounted to nearly 20,000 tons, in addition to which considerable amount of tin salts was produced. There still remains, however, opportunity for improvement in recovering waste tin.

H. L.

Air Pollution by Automobile Exhausts.—Ample evidence exists as to the dangerous nature of the exhaust gases from internal combustion engines. These differ considerably in composition, depending on the composition of the mixture of air and combustible that may be fed to the cylinders. Imperfect combustion often occurs, by which carbon monoxide, an extremely poisonous gas, is formed. Doctors Henderson and Haggard, of New Haven, Connecticut, have made and published extensive investigations into the amounts of carbon monoxide in air pollution by automobile exhausts. Their

results appeared in the *Journal of the American Medical Association* (1923, **31**, 385) under the title "Health Hazards from Automobile Exhaust Gases in City Streets, Garages and Repair Shops." In the open country, with the limited number of operating autos, pollution is not likely to be serious, but in narrow, congested city streets, and in overcrowded garages, the concentration of the products of imperfect combustion of the motor liquids is apt to be marked. Most autos discharge their exhausts horizontally about the level of the car axles, so that the air on the level of the occupants of the following car is sure to be polluted. The investigators made many tests and found that this method of discharge is decidedly objectionable. They recommend a vertical exhaust by means of a pipe directed so as to cause the exhaust to be mixed with air above the respiratory zone of the passengers. Such a modification in auto construction will, probably, not be brought about except by legislation. Henderson and Haggard suggest that the simplest and most efficient method would be taxation. If a license fee of say $25, in addition to the regular fee, was levied on all cars not provided with vertical exhaust, the condition would be promptly remedied.

The amount of visible smoke is not an index of the carbon monoxide content of the gases discharged. Chemical tests showed that the air of garages and repair shops is, as a rule, quite insanitary. Many mechanics and drivers suffer frequently from headache and other objectionable conditions due to partial asphyxiation. Fatal accidents in garages are frequently reported. The ordinary horizontal exhaust mixes poisonous gases in the air of city streets to a depth of about ten feet. It dissipates the heat of the gas and prevents it rising and passing away. The vertical exhaust is far better. H. L.

The Carbon Arc Spectrum in the Extreme Ultra-violet. F. SIMEON. (*Proc. Royal Soc.*, A 726.)—With a curved grating having 568 lines per centimetre, ruled with a light pressure so that in this respect it resembled the one with which Millikan attained his best results, the spectrum of the carbon arc has been notably extended. Not only have some dozens of new lines been photographed, but the limit of the line spectrum is now at 371.5 Å, whereas it was previously at 584 Å. "The spectrum of the carbon arc in vacuum extends as far in the extreme ultra-violet as that of the spark with the exception of a very faint line at 360.5 Å." "With thirty volts the arc would not persist, but gave a flash upon touching the carbons together." G. F. S.

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